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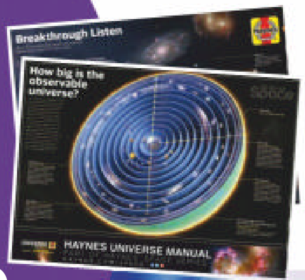
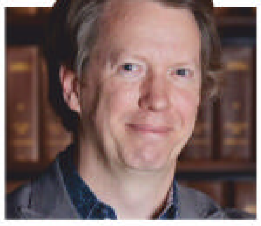


QUANTUM PHYSICS 101

Physicist Sean Carroll on 'spooky science' made easy



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Do we need to rewrite the history of our own planet?

Welcome

Searching for another universe must be my favourite initiative when it comes to exploring our cosmos, so this month I'm pleased that we've been able to revisit our search for a multiverse, presenting the latest findings and how the laws of nature vary from one 'cosmic bubble' to another.

This month we also took to social to discover what you - our readers - thought about the likelihood of us existing side-by-side to a cosmos next door. Turn to page 16 to not only uncover the results, but to read more about the latest in research and mind-boggling developments.

Elsewhere in the issue, we've still got 2020 at the forefront of our minds - this is our final issue of 2019 after all! - so we've brought you the latest telescopes, binoculars, books and other accessories that'll make your views of the night sky all the more breathtaking as we revisit the stunning deep-sky targets and Solar System members that will swing into view for both hemispheres from one season to the next.

If you're clouded out, however, there's still plenty to keep you occupied this month: from meteorite hunting in Antarctica to the possibility of scientists having to rewrite the history of our very own planet and its formation, we've got everything you need to know as we search the universe for the answers to our curious questions.

Enjoy the issue and see you next year! Be sure to keep in touch.

Gemma Lavender
Editor-in-Chief

Our contributors include...

Colin Stuart
Space science writer
We could be homing in our search for another universe. Join Colin as he reveals the details to humanity's greatest queries: could we really be the only universe?

Giles Sparrow
Space science writer
What if we are wrong about the Earth's past? That's the upshot of Giles' recent discovery as he speaks to the scientists with a whole new story.

Sean Carroll
Theoretical physicist
Need a quick guide on quantum physics? Sean provides the lowdown on what it's all about and why there should be more interest in the field.

James Romero
Science writer
James goes on the hunt for hidden quarks. Enter a subatomic universe as he reveals how an up-and-coming particle smasher could turn up surprising results.

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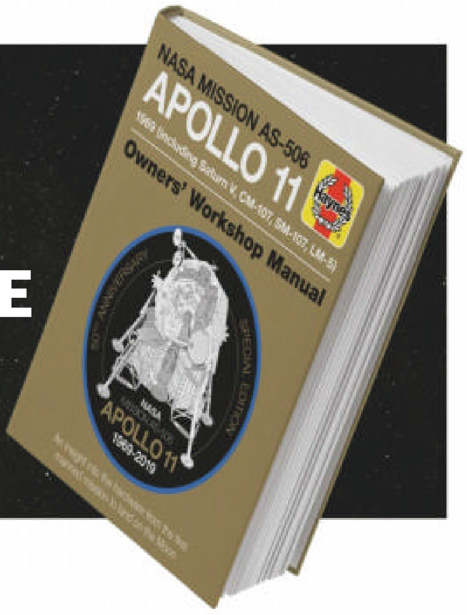
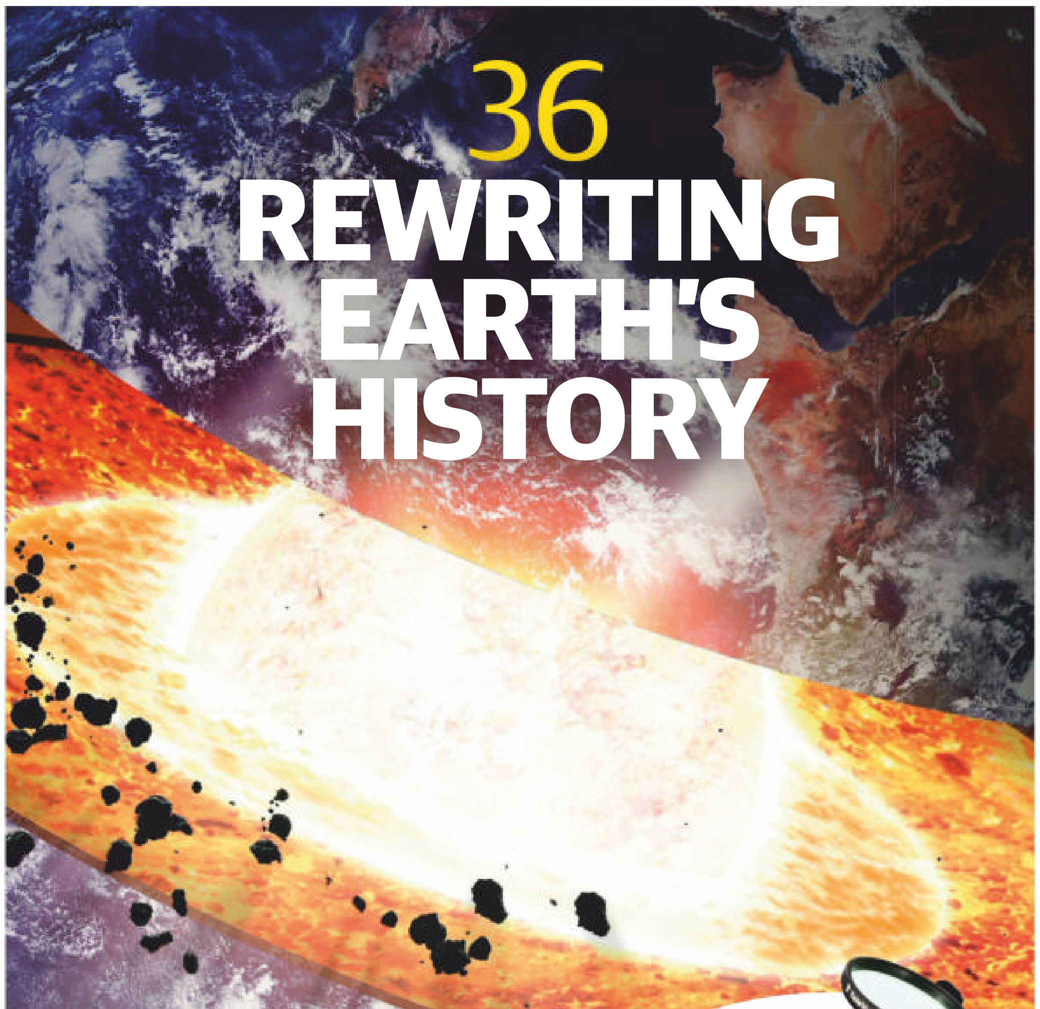


“We should always try to figure out what is going on behind the scenes”

44 Sean Carroll
Physicist and author



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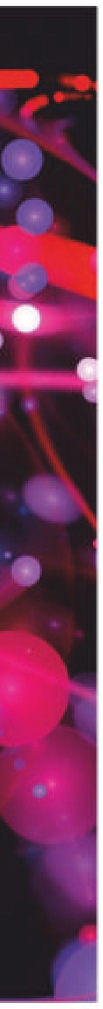

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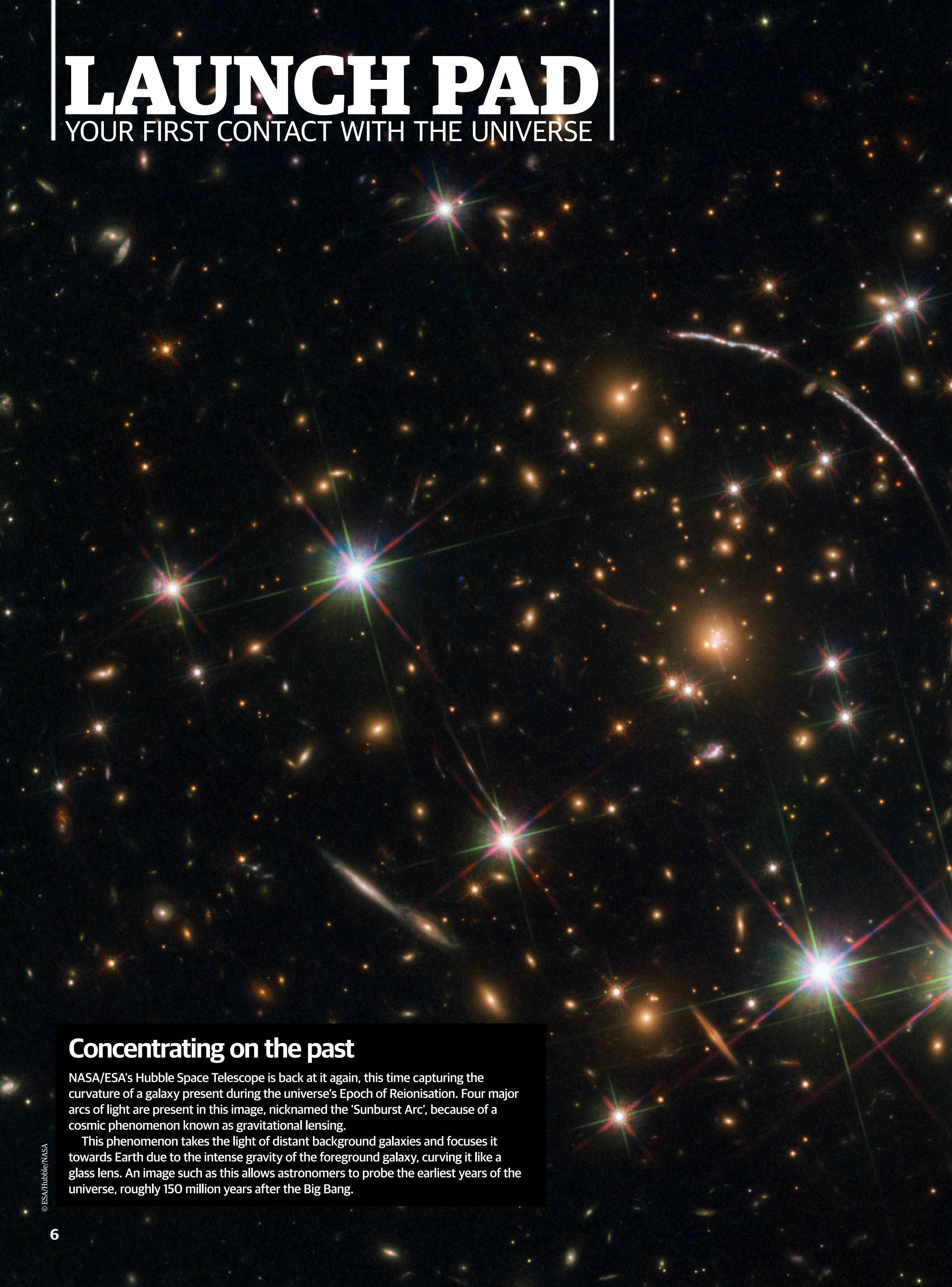
YOUR FIRST CONTACT WITH THE UNIVERSE



Concentrating on the past

NASA/ESA's Hubble Space Telescope is back at it again, this time capturing the curvature of a galaxy present during the universe's Epoch of Reionisation. Four major arcs of light are present in this image, nicknamed the 'Sunburst Arc', because of a cosmic phenomenon known as gravitational lensing.

This phenomenon takes the light of distant background galaxies and focuses it towards Earth due to the intense gravity of the foreground galaxy, curving it like a glass lens. An image such as this allows astronomers to probe the earliest years of the universe, roughly 150 million years after the Big Bang.

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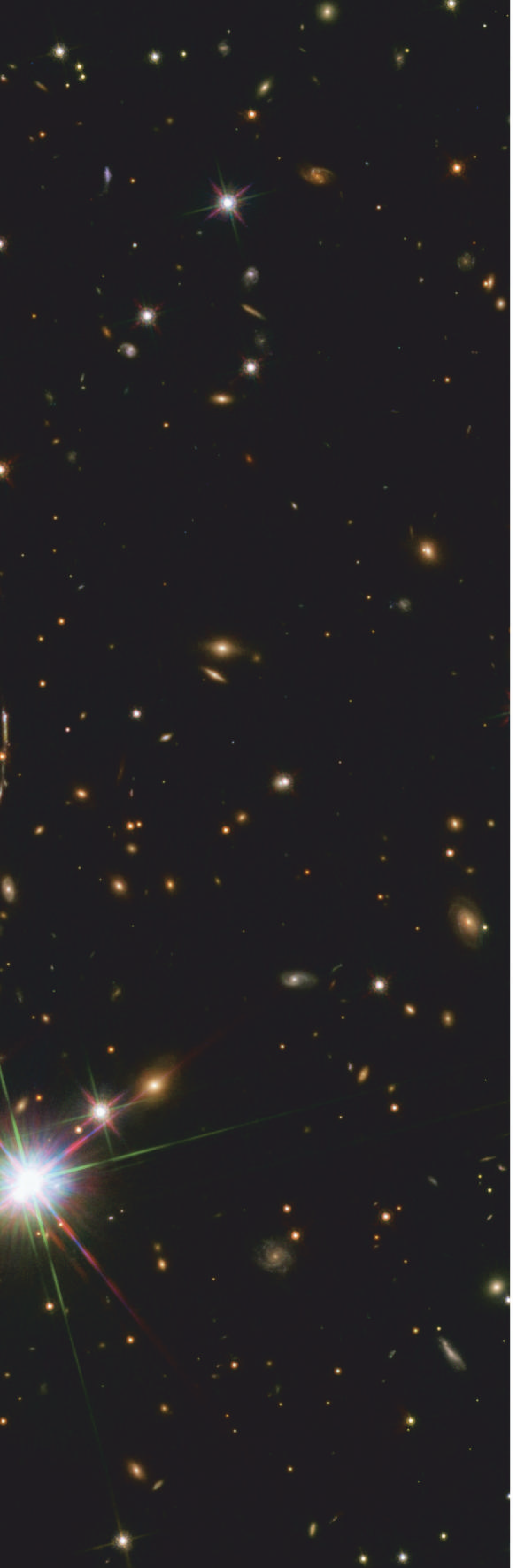

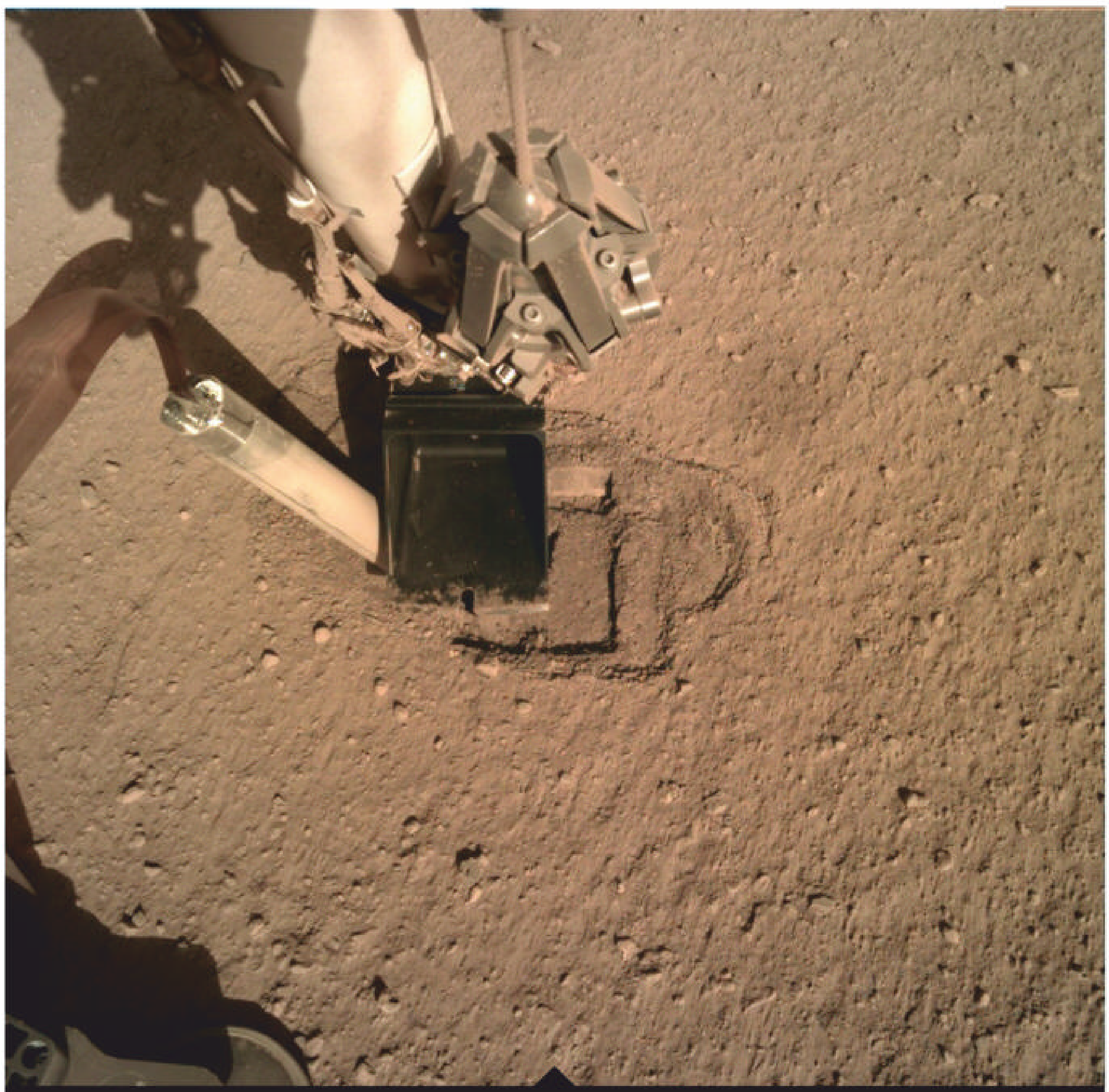

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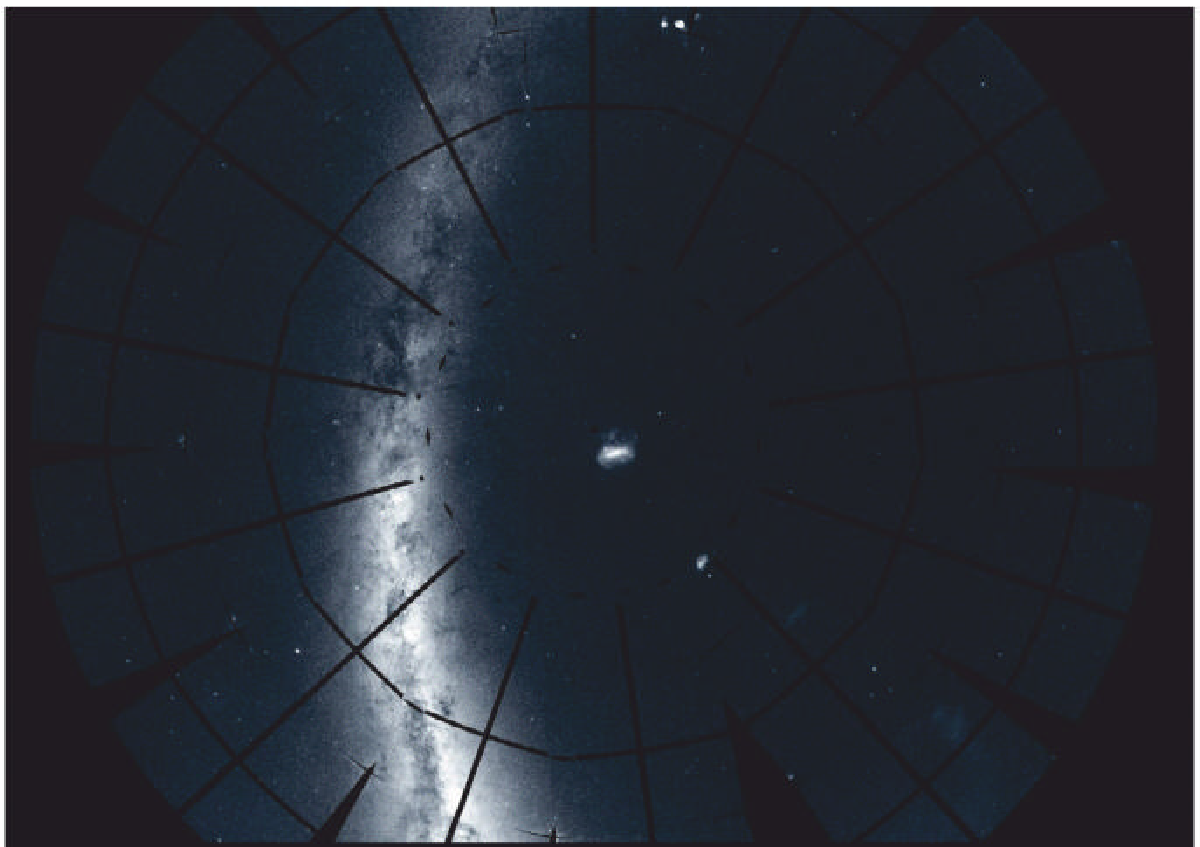
Problems with the mole

Not every mission goes entirely to plan, and NASA's Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) lander is no exception. This recent image taken by one of the onboard cameras shows part of an instrument that is meant to dig five metres (16 feet) into the Martian surface in order to measure the heat coming from within. This instrument, commonly referred to as 'the mole', has hit a snag, and can't seem to dig further than about 0.3 metres (one foot). In this image it appears to have popped out of the ground after engineers tried pinning it to the wall of the hole using InSight's robotic arm to increase friction.



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Celebrating a year in space

NASA's latest exoplanet hunter, the Transiting Exoplanet Survey Satellite (TESS), recently marked off its first anniversary of operations in space, which was celebrated by producing a mosaic image of the southern sky from TESS data.

18 July 2019 was the official anniversary of its first year of science operations, but it has taken a while to put together 208 TESS images to create this view of the southern night sky, divided into 13 sectors, showing the arc of our Milky Way.

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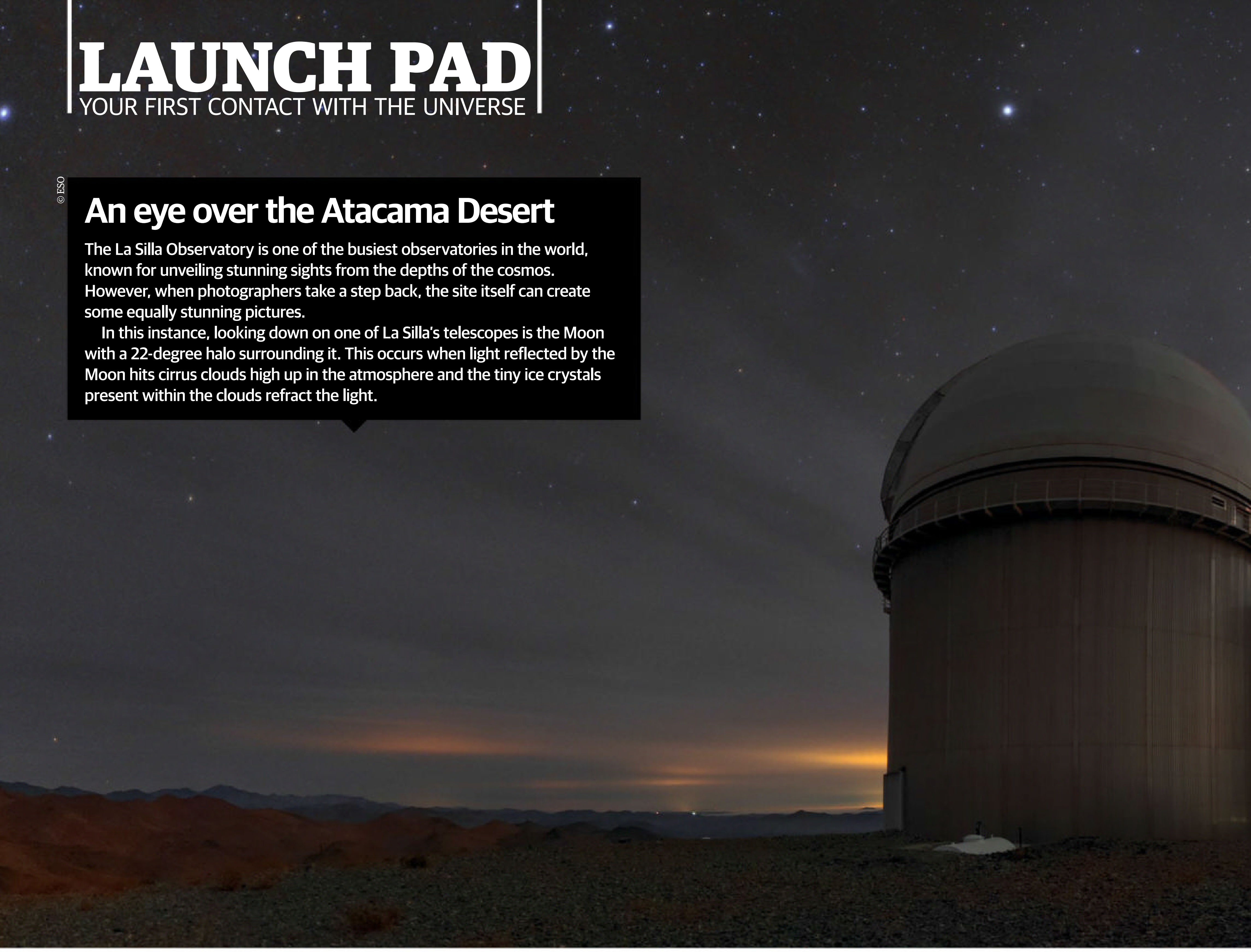

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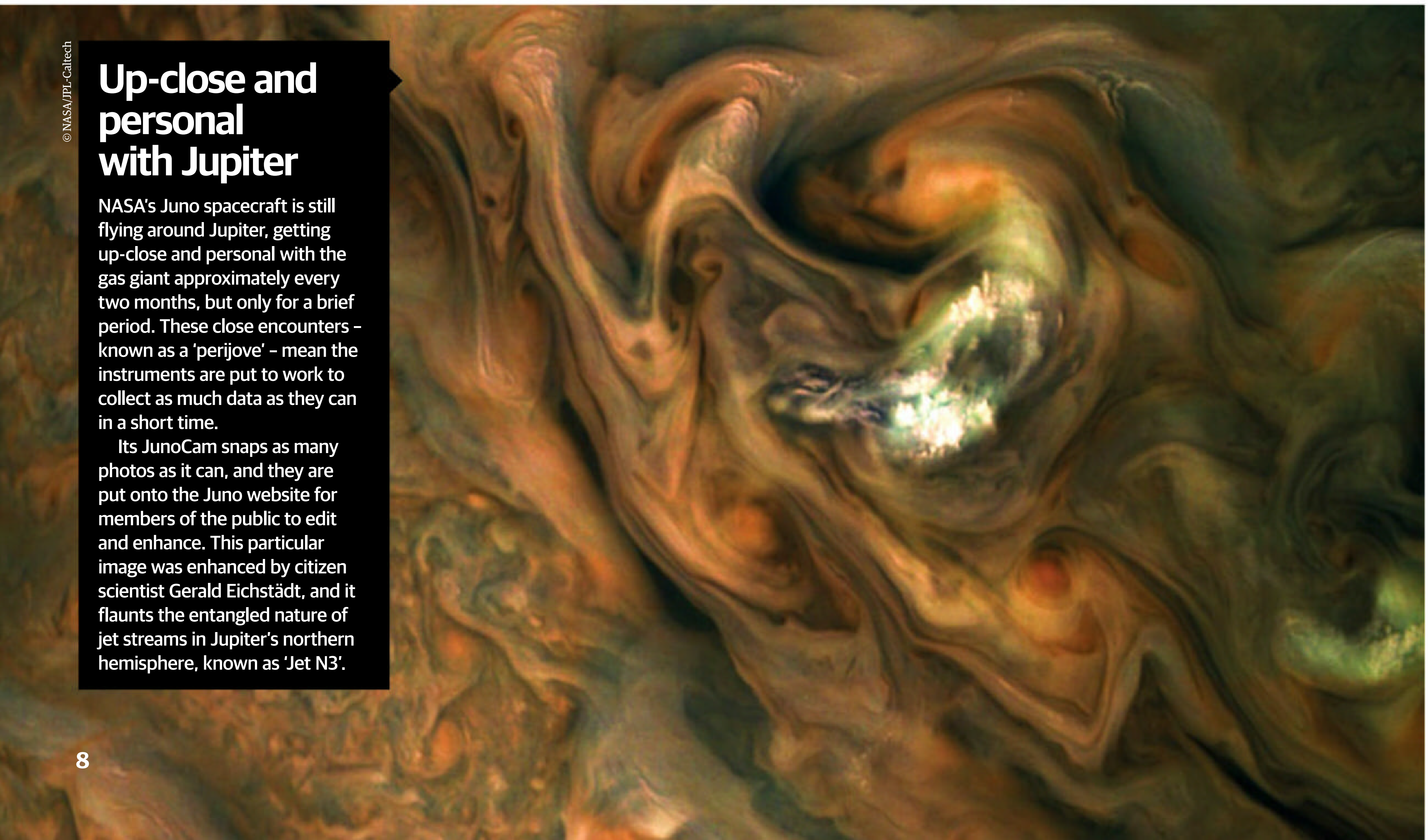
An eye over the Atacama Desert

The La Silla Observatory is one of the busiest observatories in the world, known for unveiling stunning sights from the depths of the cosmos. However, when photographers take a step back, the site itself can create some equally stunning pictures.

In this instance, looking down on one of La Silla's telescopes is the Moon with a 22-degree halo surrounding it. This occurs when light reflected by the Moon hits cirrus clouds high up in the atmosphere and the tiny ice crystals present within the clouds refract the light.



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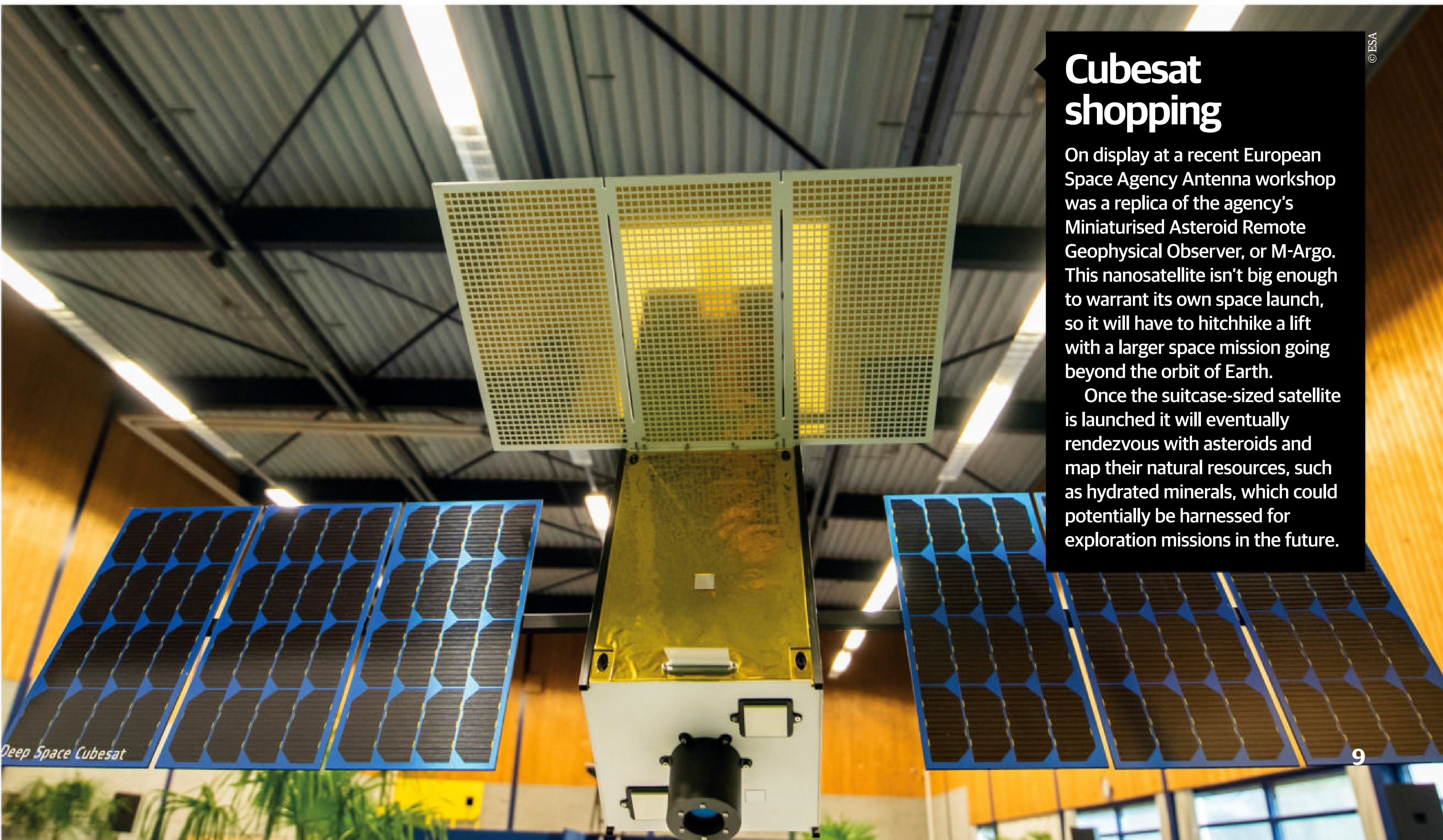
Up-close and personal with Jupiter

NASA's Juno spacecraft is still flying around Jupiter, getting up-close and personal with the gas giant approximately every two months, but only for a brief period. These close encounters – known as a 'perijove' – mean the instruments are put to work to collect as much data as they can in a short time.

Its JunoCam snaps as many photos as it can, and they are put onto the Juno website for members of the public to edit and enhance. This particular image was enhanced by citizen scientist Gerald Eichstädt, and it flaunts the entangled nature of jet streams in Jupiter's northern hemisphere, known as 'Jet N3'.



Cubesat shopping

On display at a recent European Space Agency Antenna workshop was a replica of the agency's Miniaturised Asteroid Remote Geophysical Observer, or M-Argo. This nanosatellite isn't big enough to warrant its own space launch, so it will have to hitchhike a lift with a larger space mission going beyond the orbit of Earth.

Once the suitcase-sized satellite is launched it will eventually rendezvous with asteroids and map their natural resources, such as hydrated minerals, which could potentially be harnessed for exploration missions in the future.

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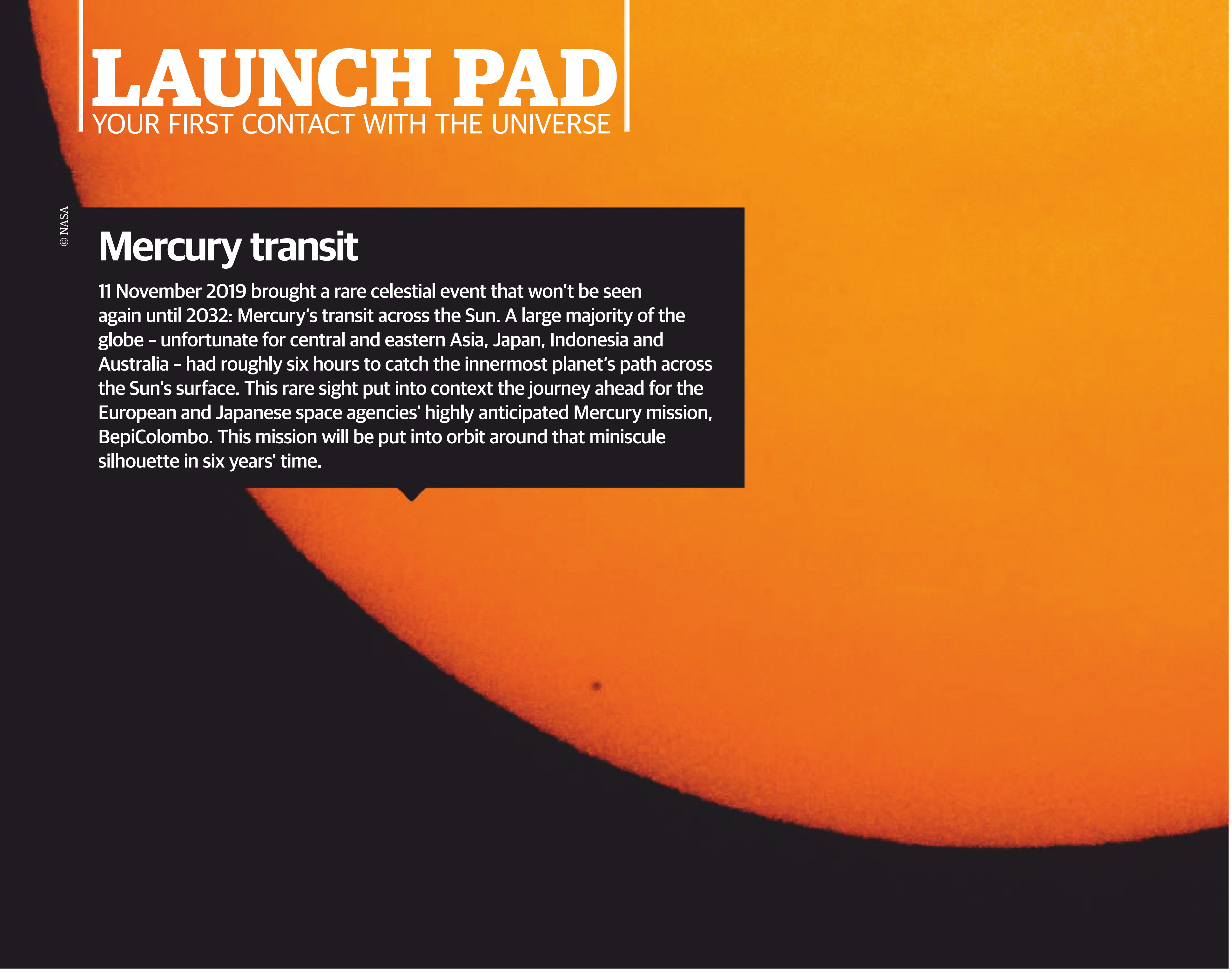

Mercury transit

11 November 2019 brought a rare celestial event that won't be seen again until 2032: Mercury's transit across the Sun. A large majority of the globe – unfortunate for central and eastern Asia, Japan, Indonesia and Australia – had roughly six hours to catch the innermost planet's path across the Sun's surface. This rare sight put into context the journey ahead for the European and Japanese space agencies' highly anticipated Mercury mission, BepiColombo. This mission will be put into orbit around that miniscule silhouette in six years' time.

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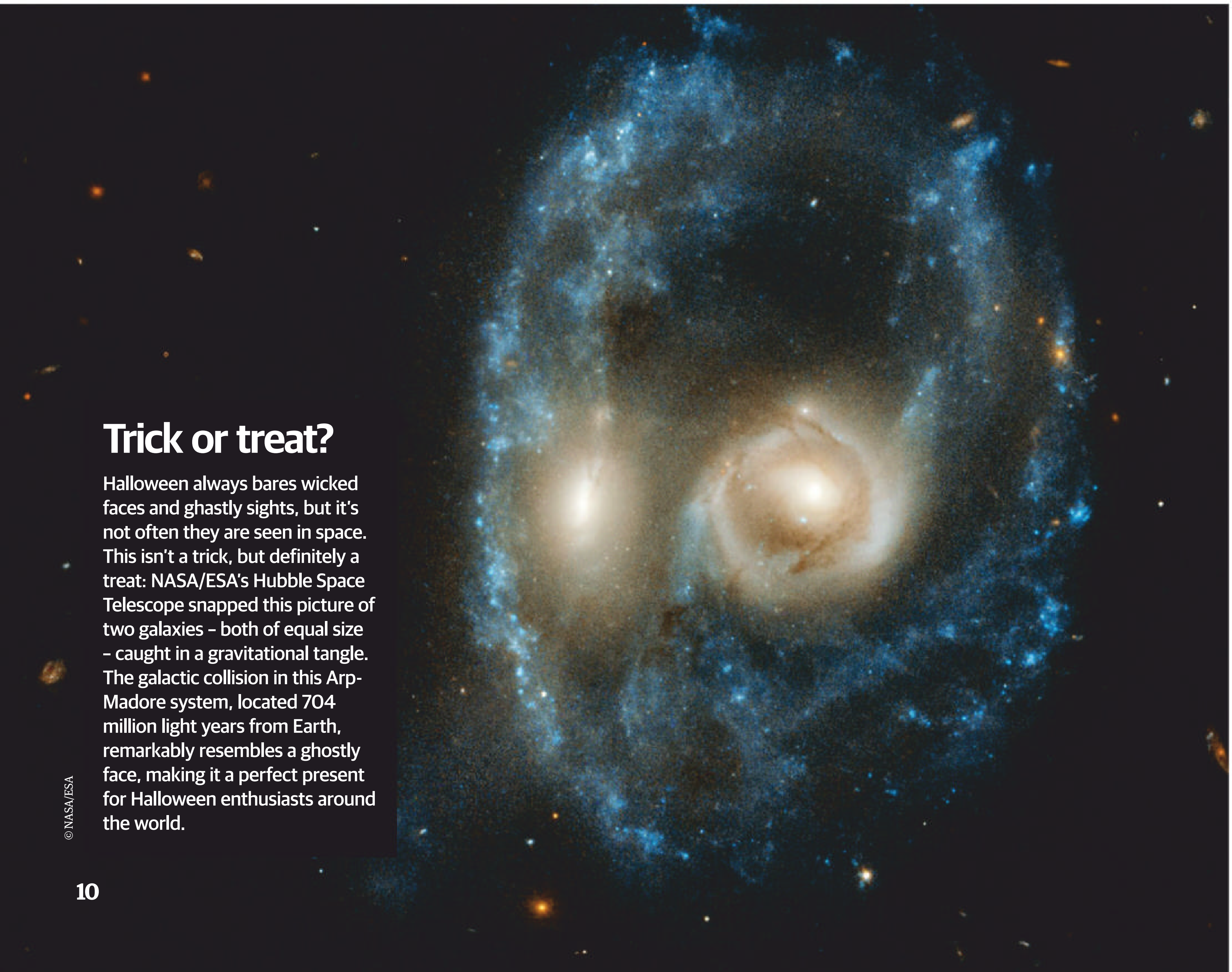

Trick or treat?

Halloween always bares wicked faces and ghastly sights, but it's not often they are seen in space. This isn't a trick, but definitely a treat: NASA/ESA's Hubble Space Telescope snapped this picture of two galaxies – both of equal size – caught in a gravitational tangle. The galactic collision in this Arp-Madore system, located 704 million light years from Earth, remarkably resembles a ghostly face, making it a perfect present for Halloween enthusiasts around the world.

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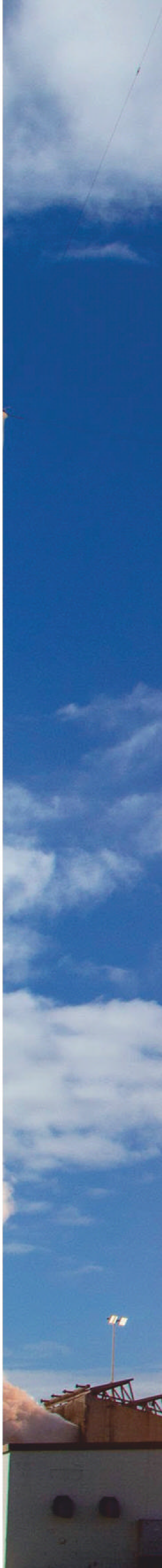


SpaceX launches more Starlink satellites

In an ambitious attempt to provide global internet coverage, Elon Musk – founder and CEO of the aerospace company SpaceX – has sent another 60 Starlink satellites into low-Earth orbit. This brings the grand total of Starlink satellites now in space to 120, but thousands more are intended to launch.

This was also a milestone for SpaceX's Falcon 9 booster, marking the fourth flight for this particular rocket. This is more than any of its competitors, and it's on course to complete its launch design of managing ten flights in total.

© SpaceX

The universe might be a giant loop

Words by **Rafi Letzter**

Everything we think we know about the shape of the universe could be wrong. Instead of being flat like a bedsheet, our universe may be curved like a massive, inflated balloon. That's the upshot of a new paper published in the journal *Nature Astronomy* which looks at data from the cosmic microwave background (CMB), the faint echo of the Big Bang. But not everyone is convinced; the new findings, based on data released in 2018, contradict both years of conventional wisdom and another recent study based on that same CMB dataset.

If the universe is curved, according to the new paper, it curves gently. That slow bending isn't important for moving around our lives, or Solar System or even our galaxy, but travel beyond all of that and eventually – moving in a straight line – you'll loop around and end up right back where you started. Cosmologists call this idea the 'closed universe'. It's been around for a while, but it doesn't fit with existing theories of how the universe works, so it's been largely rejected in favour of a 'flat universe' that extends without boundary in every direction and doesn't loop around on itself. Now, an anomaly in data from the best-ever measurement of the CMB offers solid – but not absolutely conclusive – evidence that the universe is closed after all, according to the authors: University of Manchester cosmologist Eleonora Di Valentino, Sapienza University of Rome cosmologist Alessandro Melchiorri and Johns Hopkins University cosmologist Joseph Silk.

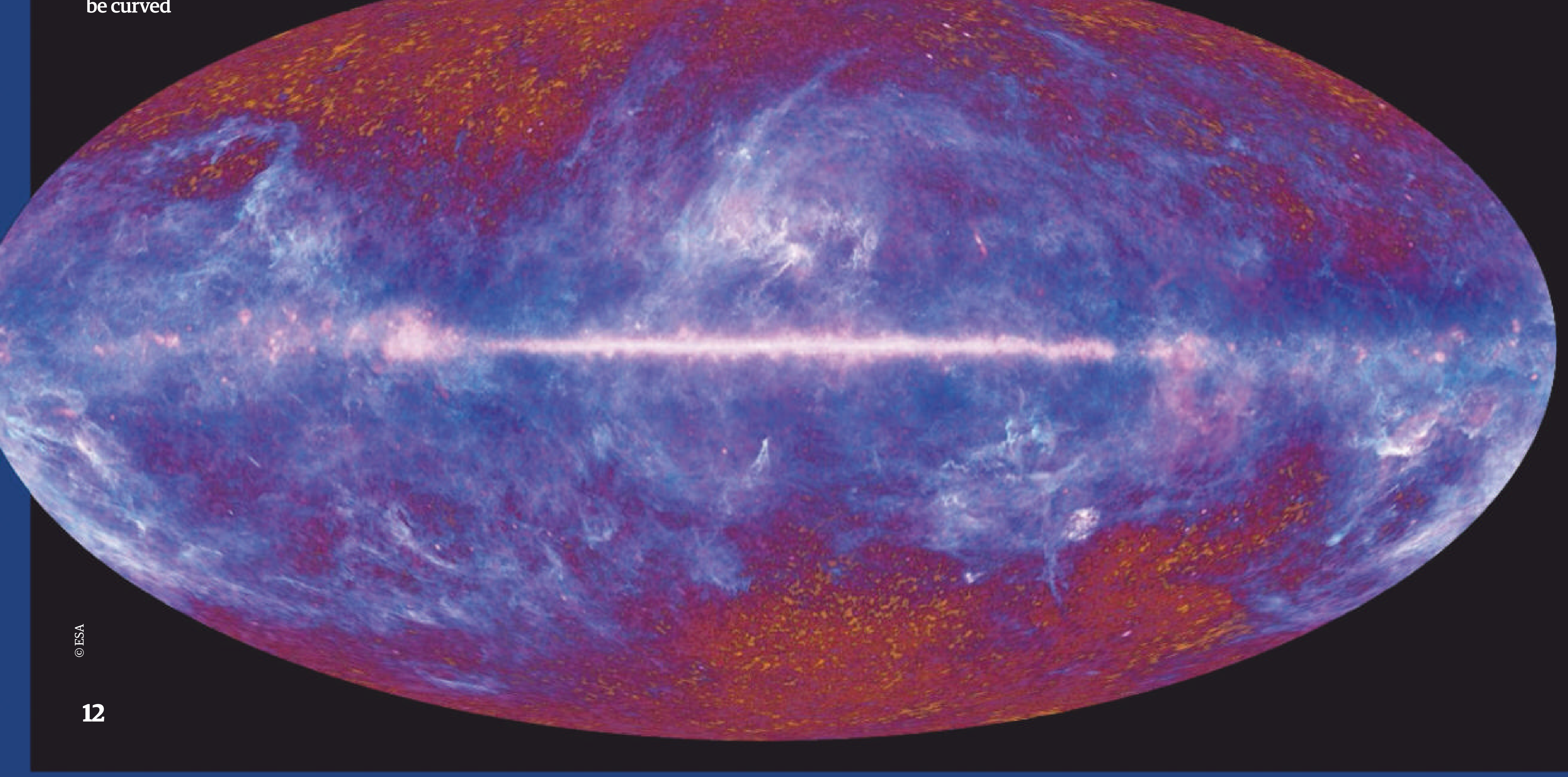
The difference between a closed and open universe is a bit like the difference between a stretched flat sheet and an inflated balloon, Melchiorri told **Live Science**. In either case, the whole thing is expanding. When the sheet expands, every point moves away from every other point in a straight line. When the balloon is inflated, every point on its surface gets farther away from every other point, but the curvature makes the geometry of that movement more complicated. "This means, for example, that if you have two photons and they travel in parallel in a closed universe, they will [eventually] meet," Melchiorri said. In an open, flat universe, the photons, left undisturbed, would travel along their parallel courses without ever interacting.

The conventional model of the universe's inflation, Melchiorri said, suggests that the universe should be flat. Rewind the expansion of space all the way to the beginning to the first 0.0000000000000000000000001 seconds after the Big Bang, according to that model, and you'll see a moment of incredible, exponential expansion as space grew out of that infinitesimal point in which it began. And the physics of that superfast expansion point to a flat universe. That's the first reason most experts believe the universe is flat, he said. If the universe isn't flat, you have to 'fine-tune' the physics of that primordial mechanism to make it all fit together – and redo countless other calculations in the process, Melchiorri said.

But that might end up being necessary, the authors wrote in the new study. That's because there's an anomaly in the CMB. The CMB is the oldest thing we see in the universe, made of ambient microwave light that suffuses all of space when you block out the stars and galaxies and other interference. It's one of the most important sources of data on the universe's history and behaviour because it's so old and so spread throughout space. And it turns out, according to the latest data, that there's significantly more 'gravitational lensing' of the CMB than expected – meaning that gravity seems to be bending the microwaves of the CMB more than existing physics can explain.

> "Gravity seems to be bending the microwaves of the CMB more than existing physics can explain"

The universe may actually be curved



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Both Voyagers have now passed into interstellar space

© NASA/JPL

NASA's Voyager spacecraft may only have five years left

Words by **Meghan Bartels**

The twin Voyager probes have about five years before they fall silent, when they'll no longer be able to send word of their adventures back. The Voyagers' journey will continue indefinitely, but we will no longer travel with them. "It's cooling off. The spacecraft is getting colder all the time and the power is dropping," Ed Stone, the mission's project scientist and a physicist at Caltech, said during a news conference held on 31 October in conjunction with the publication of a handful of new scientific papers. "We know that somehow, in another five years or so, we may not have enough power to have any scientific instruments on any longer."

Their success is unprecedented, even by NASA standards; the mission has lasted for two-thirds of the agency's existence. "We're certainly surprised, but also wonderfully excited by the fact they do [still work]," Stone said. "When the two Voyagers were launched, the Space Age was only 20 years old, so it was hard to know at that time that anything could last over 40 years."

Stone spoke to mark the publication of the first batch of scientific papers comparing the two crossings. The twin spacecrafts' transitions to interstellar space have been similar, but not identical, variations on a theme that humans have no concrete plans to experience again anytime soon. Unless something very dramatic happens in the universe around us, Pluto veteran New Horizons, like the Pioneer spacecraft before it, will fall silent long before it escapes our little bubble, the heliosphere.

What the Voyager mission has made clear is that two crossings are hardly enough to begin understanding this bubble - and that the spacecraft have completely changed what we know about it.

India has a new planetary target in mind: Venus

Words by **Meghan Bartels**

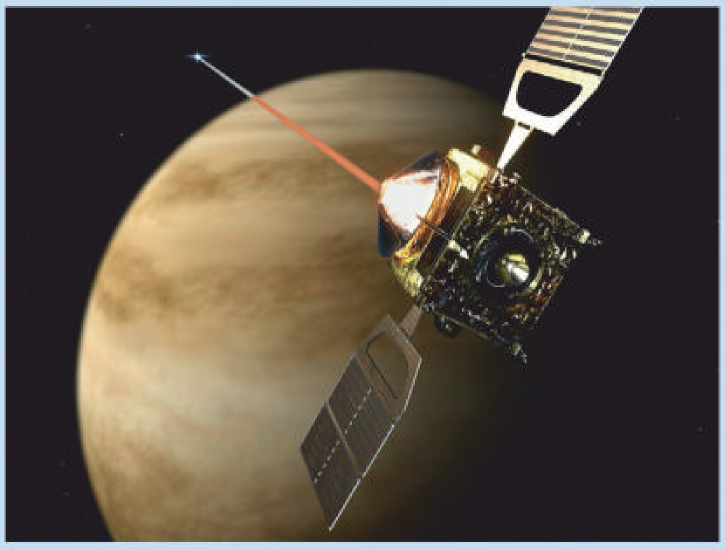
India is already eyeing a new destination. Scientists and engineers at the Indian Space Research Organisation (ISRO) have sent plans for a Venus orbiter to the Indian national government and are hoping they'll get approval to go ahead with the mission. The spacecraft could launch in just a few years and would carry more than a dozen instruments.

"The major objective is to map the Venusian surface and subsurface," Nigar Shaji, an ISRO scientist, told a group of Venus experts during a meeting held this week in Colorado. According to Shaji, the Venus orbiter that ISRO is designing would be able to create such a dataset for Venus in about a year. In addition to mapping the surface itself, looking a bit deeper into the planet should help scientists identify volcanic hotspots scattered across Venus.

Instruments on board the spacecraft would also study the planet's atmosphere and ionosphere, as well as how Venus interacts with the surrounding environment, Shaji said. ISRO has identified 16 instruments from Indian scientists that it would like to fly. Those include instruments focused on monitoring clouds, identifying lightning strikes, studying the eerie airglow of the planet and measuring the highly charged plasma particles passing by Venus on their way out from the Sun.

If the mission is approved the spacecraft could launch as soon as June 2023 on one of ISRO's Geosynchronous Satellite Launch Vehicles, the same type of vehicle that launched India's Chandrayaan-2 mission to the Moon this summer.

In India's history of launches, that spacecraft followed its predecessor, which launched in 2009, and the Mars Orbiter Mission, which launched in 2013. ISRO has also discussed returning to the Red Planet, but preliminary timelines suggest that such a mission would likely launch after the Venus orbiter.



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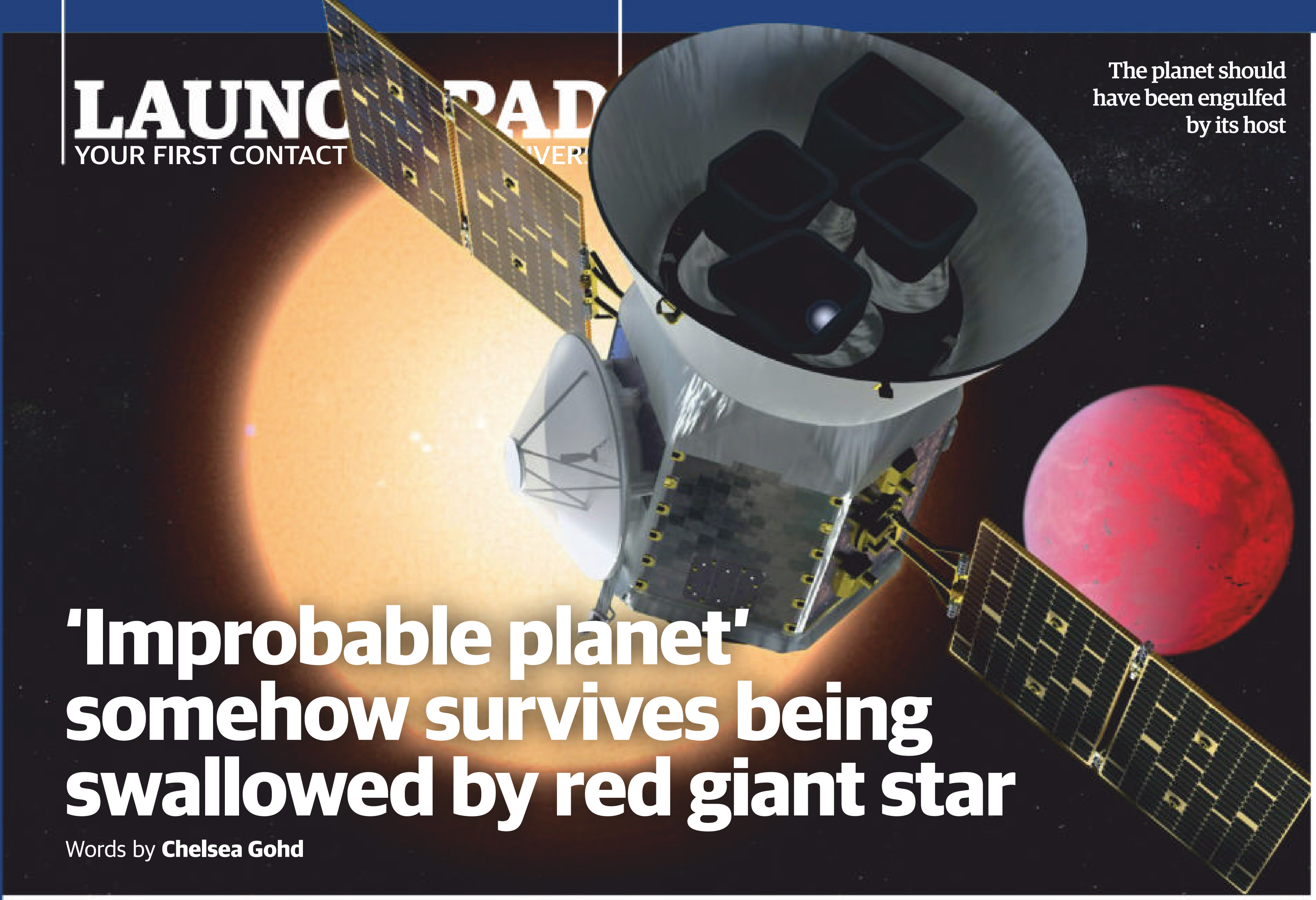


The planet should have been engulfed by its host

© NASA

'Improbable planet' somehow survives being swallowed by red giant star

Words by **Chelsea Gohd**

Using astroseismology data from NASA's Transiting Exoplanet Survey Satellite, or TESS, a team of researchers studying the red giant stars HD 212771 and HD 203949 detected oscillations. This is the first time that oscillations have been found by TESS in stars that host exoplanets.

Because these stars have orbiting exoplanets, the investigation was able to go even deeper. "TESS observations are precise enough to allow measuring the gentle pulsations at the surfaces of stars. These two fairly evolved stars also host planets, providing the ideal testbed for studies of the evolution of planetary systems," Tiago Campante of the Instituto de Astrofísica e Ciências do Espaço and Faculdade de Ciências da Universidade do Porto, told **space.com**. But one of these systems, HD 203949 and its orbiting exoplanet, sparked confusion. In studying the star, the researchers uncovered details about the star's mass, size and age. They concluded that - given its size, the stage it was at in stellar evolution and the distance of its orbiting exoplanet - the envelope of the red giant star should have theoretically engulfed the exoplanet.

But while analysis of the star shows that this planet shouldn't exist, further investigation shows that the planet somehow did avoid engulfment. To pinpoint the exoplanet's location and to confirm that it must be surviving getting swallowed by the star, Dimitri Veras of the University of Warwick's Department of Physics performed numerical simulations of the system, which the team analysed.

"We determined how this planet could have reached its current location, and to do so whether or not the planet had to survive engulfment within the stellar envelope of the red giant star. The work sheds new light on the survivability of planets when their parent stars begin to die, and might even reveal new aspects of tidal physics," Veras said in the statement.

NASA eyes a possible return to Pluto

Words by **Mike Wall**

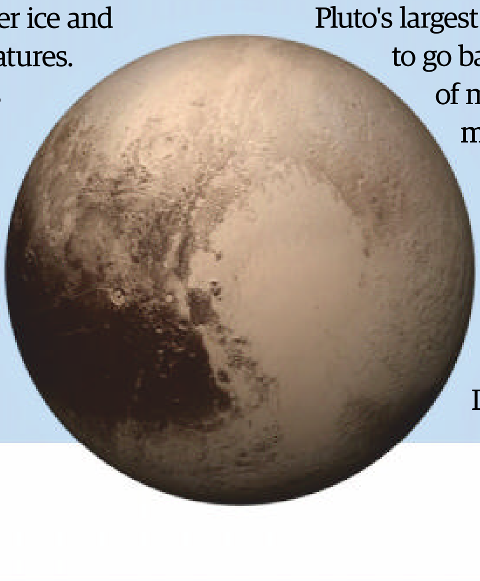
NASA is thinking about going back to Pluto, this time to stay for a while. The space agency has funded the Southwest Research Institute (SwRI) to conduct a wide-ranging study into a possible Pluto orbiter mission. The study will lay out design and instrument requirements and investigate the feasibility and costs of the potential project, SwRI representatives said.

SwRI leads NASA's New Horizons mission, which zoomed past Pluto in July 2015, snapping the first-ever up-close photos of the dwarf planet. The historic flyby revealed Pluto to be a surprisingly diverse and complex world, with 3.2-kilometre (two-mile) mountains of water ice and vast plains of nitrogen ice, among other features.

On 1 January of this year, New Horizons conducted a second flyby, this time of the small Kuiper Belt object (KBO) 2014 MU69, which is informally known as Ultima Thule. "We're excited to have this opportunity to inform the decadal survey deliberations with this study," study team leader Carly Howett of SwRI said in a statement. "Our mission concept is to send a single spacecraft to orbit Pluto for two Earth years before breaking away to visit at least one KBO and one other KBO dwarf planet."

"In an SwRI-funded study that preceded this new NASA-funded study, we developed a Pluto system orbital tour, showing the mission was possible with planned-capability launch vehicles and existing electric propulsion systems," SwRI's Alan Stern, principal investigator of the New Horizons mission and the earlier SwRI-funded study, said in the same statement.

"We also showed it is possible to use gravity assists from Pluto's largest moon, Charon, to escape Pluto orbit and to go back into the Kuiper Belt for the exploration of more KBOs like MU69 and at least one more dwarf planet for comparison to Pluto," Stern added. The newly announced NASA funding doesn't mean a Pluto orbiter will definitely be on the space agency's docket, however. NASA has also sponsored nine other mission studies to get ready for the next Planetary Science Decadal Survey.



Sun as lens could check for alien life

Words by **Meghan Bartels**

Our Sun may be able to shed light on whether life is hiding on a distant planet, assuming humans can execute a delicate manoeuvre in space.

Astrobiologists searching for signs of life beyond Earth target biosignatures, characteristics most likely caused by life. But scientists are excellent at hypothesising alternative, nonlife processes for creating biosignatures, which means identifying these characteristics on distant worlds isn't a guarantee you've found life.

"We want to find a way to get closer," Sara Seager, an astronomer at the Massachusetts Institute of Technology, said. "We want to get another look. We don't really have any ways to do that now." Seager referenced one possible solution to that quandary: designing tiny satellites that can be pushed on laser beams to make interstellar journeys. "Another idea is to use the Sun as a gravitational lens," Seager said.

Astronomers often use galaxies as gravitational lenses. The technique relies on three celestial objects lining up precisely. There's the instrument itself on or around Earth. The second is a massive galaxy or galaxy cluster, containing so much mass that its gravity warps the path of light. The third point in the line is a distant object that astronomers want to see in more detail. When these players snap into alignment, scientists can capture much sharper images of the target.

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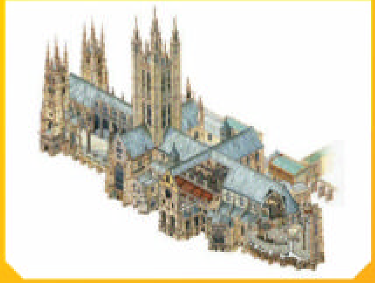

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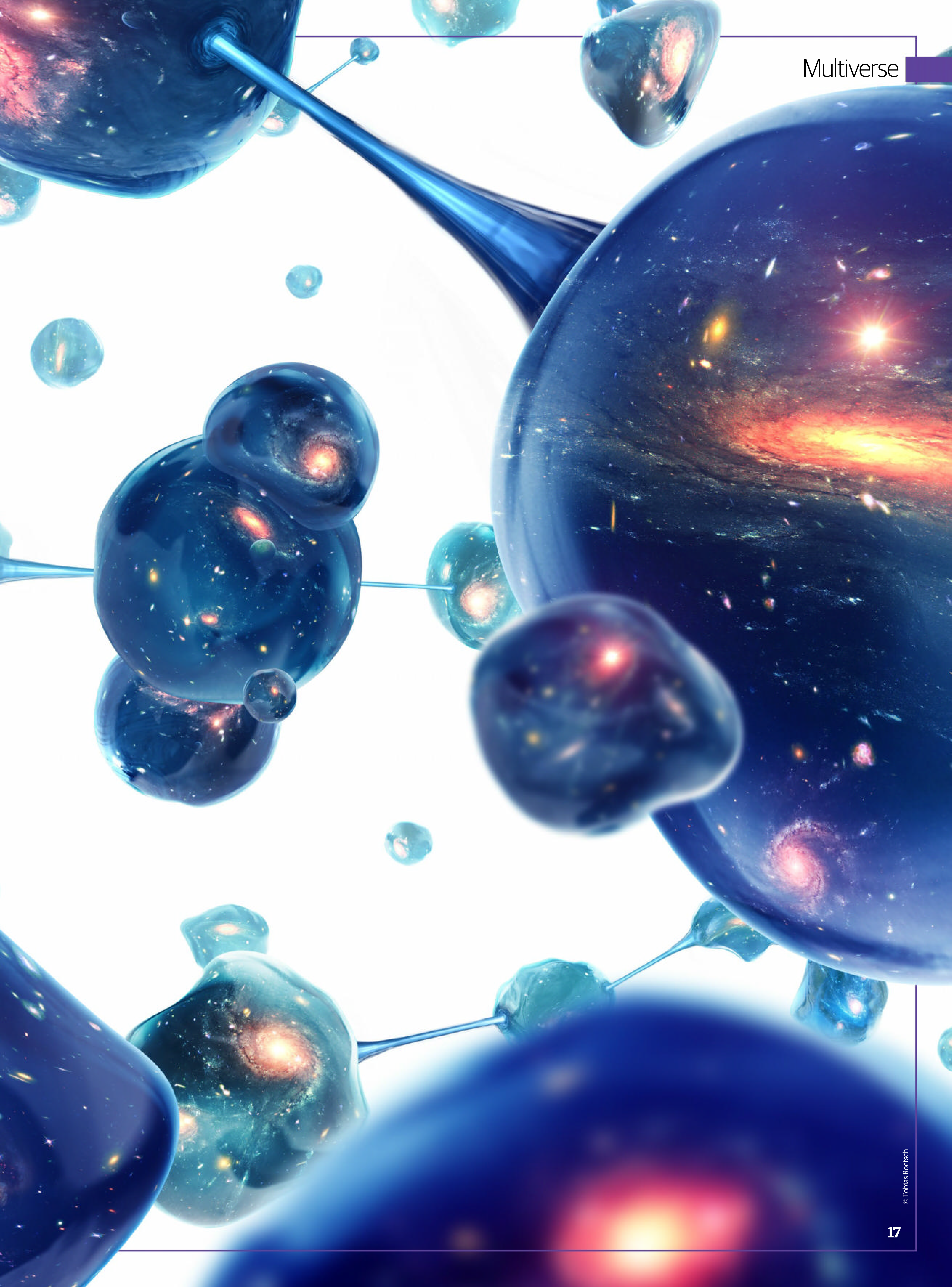
HUNT FOR THE MULTIVERSE

Could there be another you reading this article somewhere out there in space?

Reported by Colin Stuart



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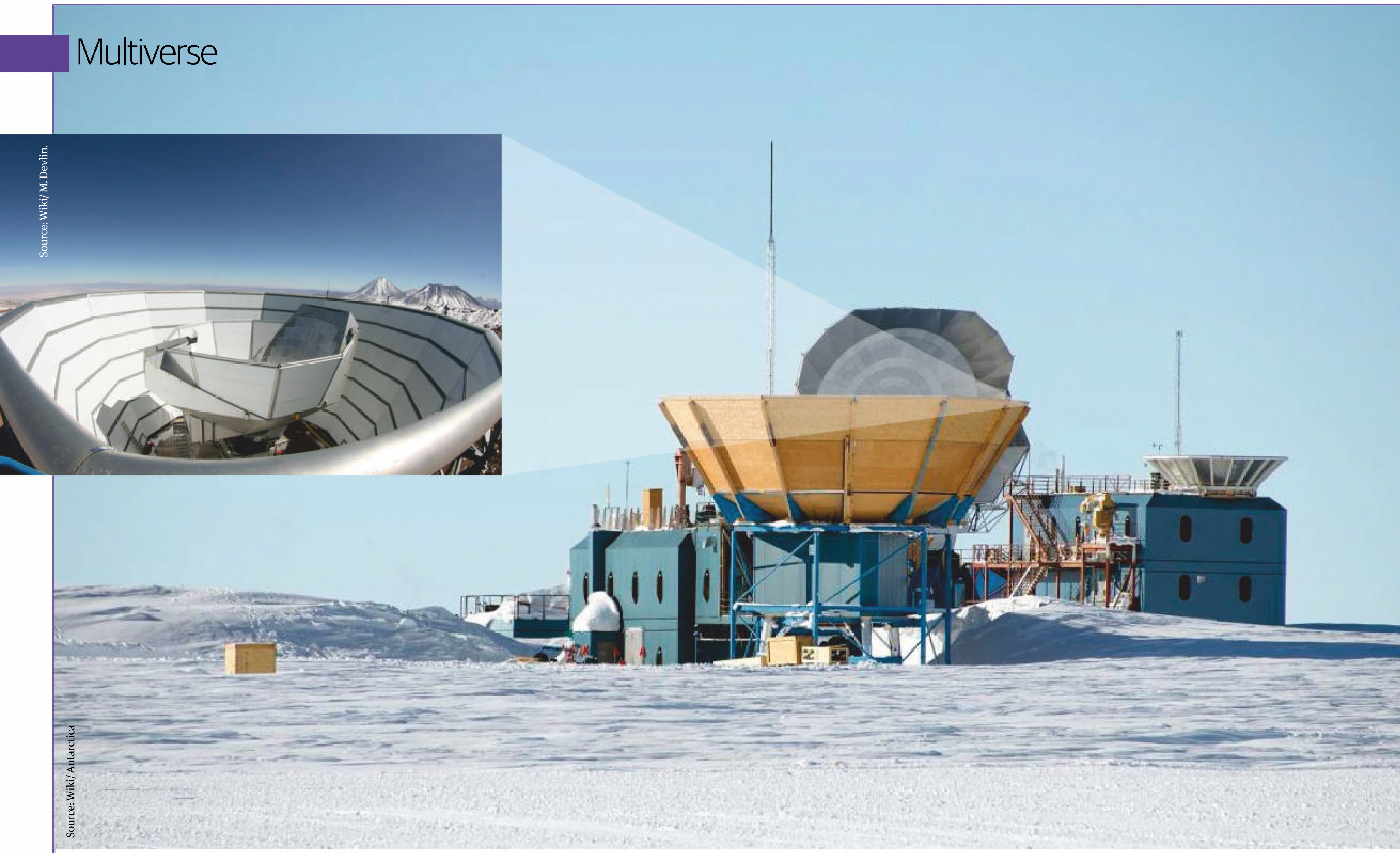
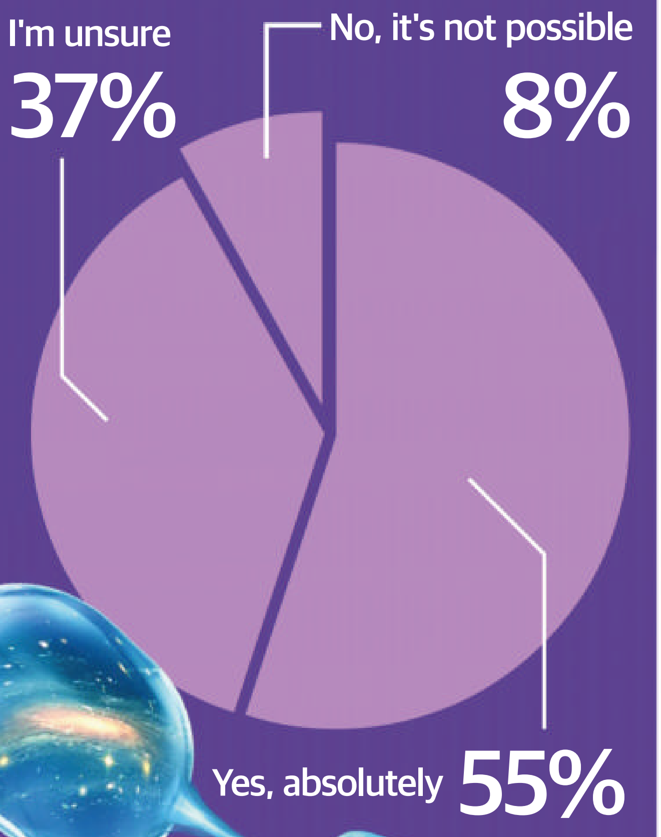


Source: Wiki/ M. Devlin.

Source: Wiki/ Antarctica

We asked you...

Do you think we live in a multiverse?



Cosmonaut Alexei Leonov descends to the foot of the ladder before placing his boots into the grey dust. His words are beamed back to Earth and ring out of television and radio sets across the planet. "For my country, my people and the Marxist-Leninist way of life," he says, as the hammer-and-sickle flag stands proudly behind him. For the first time in history human beings have finally set foot on the Moon.

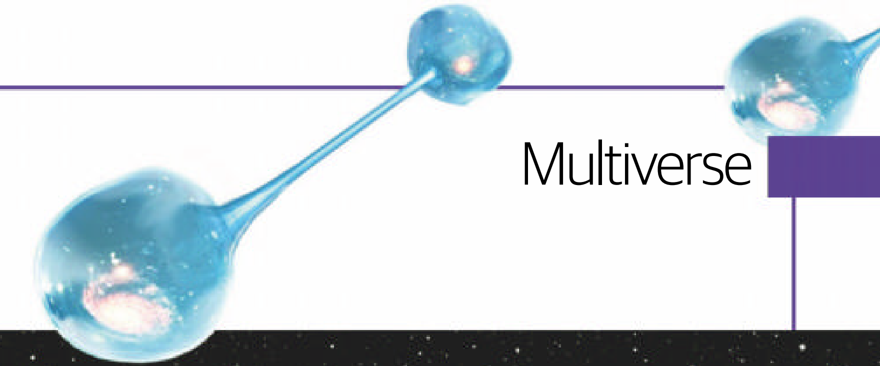
If you're scratching your head knowing full well that the Soviets didn't land people on the lunar surface, this is the historical twist on which the new Apple TV drama *For All Mankind* rests: the Americans were beaten to the Moon, and the storyline follows the resulting fallout. Yet there's a chance that these events really did take place - just not in our universe. Many cosmologists increasingly suspect that 'the' universe should really be replaced with 'our' universe, one of many in a complex landscape of cosmoses called the multiverse.

If there are enough of them, eventually you'll end up in a universe where events repeat. In others history will be eerily similar, but with small variations such as the Soviets getting to the Moon first, you becoming US president or having three arms. It all boils down to the fact that there are only a finite number of ways to arrange things. Imagine a room containing ten objects in a line. There are 3,628,800 unique ways to arrange those ten objects. If you have four million rooms, it is guaranteed that in at least two of them the objects will be in the same configuration. Equally, there are only a limited number of ways you can arrange atoms in a universe. If there are a large number of other universes, eventually you will get a copy of this one. That means an exact replica of you reading an identical copy of this article.

Strictly speaking you don't need the multiverse for this unsettling reality to hold true. Even if our universe is the only one, if it's big enough, travel far enough and it becomes a statistical certainty that events repeat. Just like if you visited every home on Earth to see how each one's objects are arranged, you wouldn't need another Earth to ensure that you found a repeat. How far do you have to go into this universe to find another you? It's much further than the boundary of the observable universe, so there's no prospect of running into your doppelgängers. Cosmologists call this a Level I parallel universe, and it's the simplest model of a multiverse.

A Level II parallel universe is a separate cosmos created by the same process that spawned ours, and for that we need to look back to the Big Bang, and a period called inflation in particular. "If our universe was created by inflation then billions of others were too," says Tom Shanks from the University of Durham. "We have to test that theory." Inflation is the idea that our infant universe underwent a short burst of souped-up expansion. In a trillionth of a trillionth of a trillionth of a second it ballooned from smaller than an atom to the size of a grapefruit.

That may not sound like much, but if you increased the size of a red blood cell by the same amount then it would be larger than the entire observable universe. Physicists have spent the last 40 years examining the mechanisms that could have caused the universe to blow up in this way. In most theories the process of inflation is eternal - once started it can never be fully stopped. If true, that means it is still creating universes to this day,



> “If our universe was created by inflation then billions of others were too. We have to test that theory”

Professor Tom Shanks

forever adding new members to an already crowded multiverse. According to string theory, the number of other universes could run to as many as one with 500 zeroes following it.

It may sound a little farfetched, and frankly intimidating, but there are ways in which it may be possible to test the idea of a multiverse. Many have turned to the cosmic microwave background (CMB) - the afterglow of the Big Bang - for help. A map of this radiation is speckled with hot and cold spots, and almost all of them are of a similar size. Yet one stands out like a sore thumb - a huge cold spot in the southern sky towards the constellation of Eridanus. If our eyes could see the CMB, this cold spot would appear ten-times wider than the full Moon. Not everyone agrees that it’s real. Some have suggested it is a ghost in the data, the result of the statistical analysis carried out by researchers.

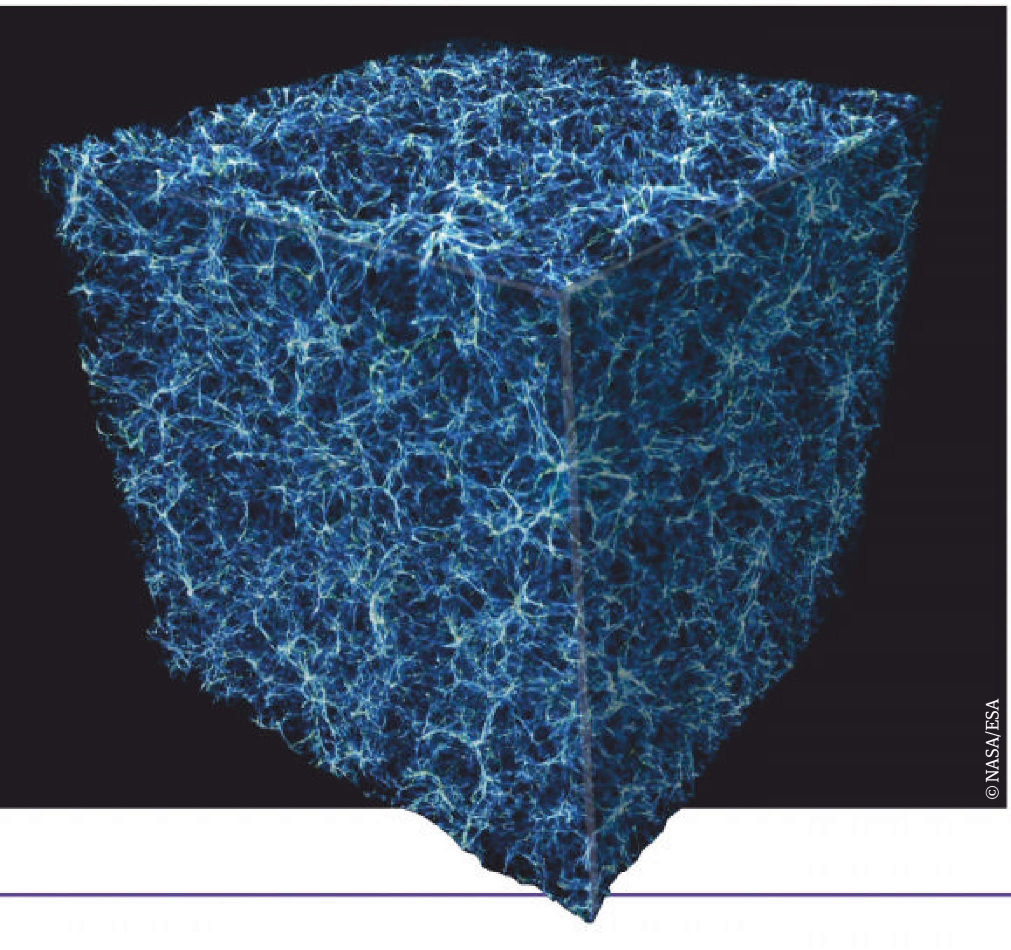
If it’s really there, the simplest explanation of the cold spot is that there is an unusually huge patch of empty space between us and the origin of the CMB. As the light from the early universe passed through this barren zone it would have been robbed of some of its energy, leading us to see an abnormally large cold spot in the CMB. That's exactly what Shanks and his team set out to test.

In 2017 they released details of an extensive survey of galaxies in that direction. They found it to be no more underpopulated than anywhere else in the universe. So what is causing the cold spot? “The next most standard explanation is a bubble collision,” says Shanks. That's a collision between this universe and a neighbouring one created by the process of inflation at a very similar time to ours. The multiverse could quite literally have left

Left: This instrument is searching for polarisation signals in the cosmic microwave background

Left (inset): Controversial experiment that incorrectly claimed evidence of inflation back in 2014

Below: A universe of clusters and voids. A large void was the simplest explanation of the CMB’s cold spot



© NASA/ESA

Our hunt for another universe

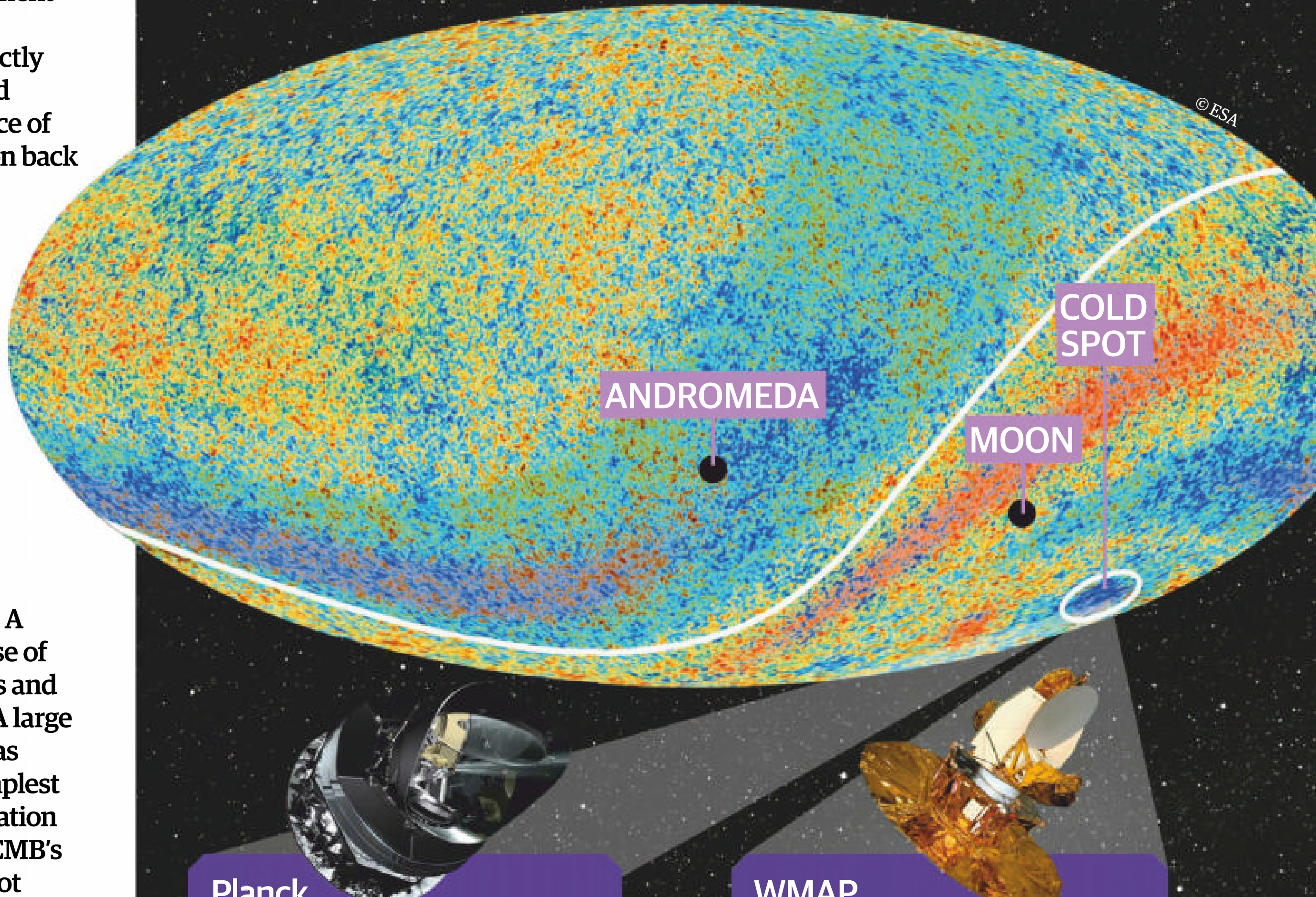
There have already been some hints that we live in a multiverse

Is inflation an eternal process?

Inflation – a period of rapid initial expansion – is a modification to the theory of the Big Bang which makes it easier to explain the resulting universe we observe. Most models of inflation suggest it is a never-ending process – where you get one universe you get many.

Cosmic microwave background cold spot

Most temperature variations in the CMB are small, yet there is an unusually large one in the Southern Hemisphere sky. Some researchers point to it as evidence of a collision between our universe and another, although that idea continues to be the subject of fierce debate.



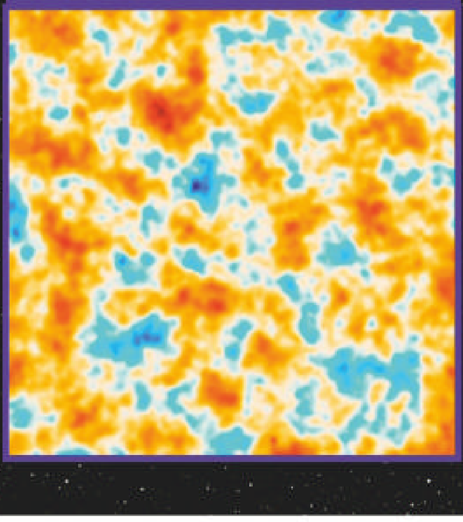
Planck

Launch: 14 May 2009

Mission objectives: Map the temperature variations in the CMB in unprecedented detail.

Notable achievements: Best map of the CMB to date.

Mission ended: 2013



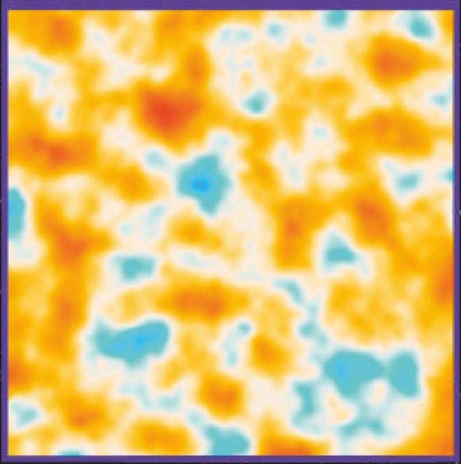
WMAP

Launch: 30 June 2001

Mission objectives: Map the cosmic microwave background.

Notable achievements: Finding evidence for dark energy and the age of the universe.

Mission ended: 2010



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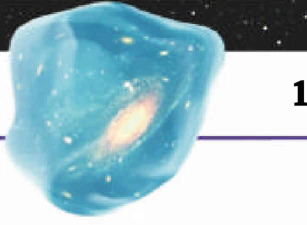

What happens in other universes?

Physicists have contemplated different levels of multiverse created by different physics processes

Level I

Even if there is only one universe, there could still be exact copies of this planet knocking around. As there are only a finite number of ways of arranging things, in an infinitely big universe repeats are guaranteed to occur.

What happens inside this universe?
Everything that happens in the observable universe is repeated an infinite number of times. Also, every possible combination of events can unfold an infinite number of times. There are planets where you don't exist, but also those where you do and you're the ruling monarch of the universe or a sentient slug – or even both.

Level II

The process of eternal inflation is constantly blowing up new universes like balloons. Our tiny, infant universe went from too small to see to something you could hold in your hand in a fraction of a second before continuing to expand more sedately.

What happens inside this universe?
Most agree that the laws of physics and the properties of particles would differ in each universe. The majority would be unlike ours, but there will be exact copies, meaning lots of identical yous. Others will be near copies in which famous historical events unfolded differently.

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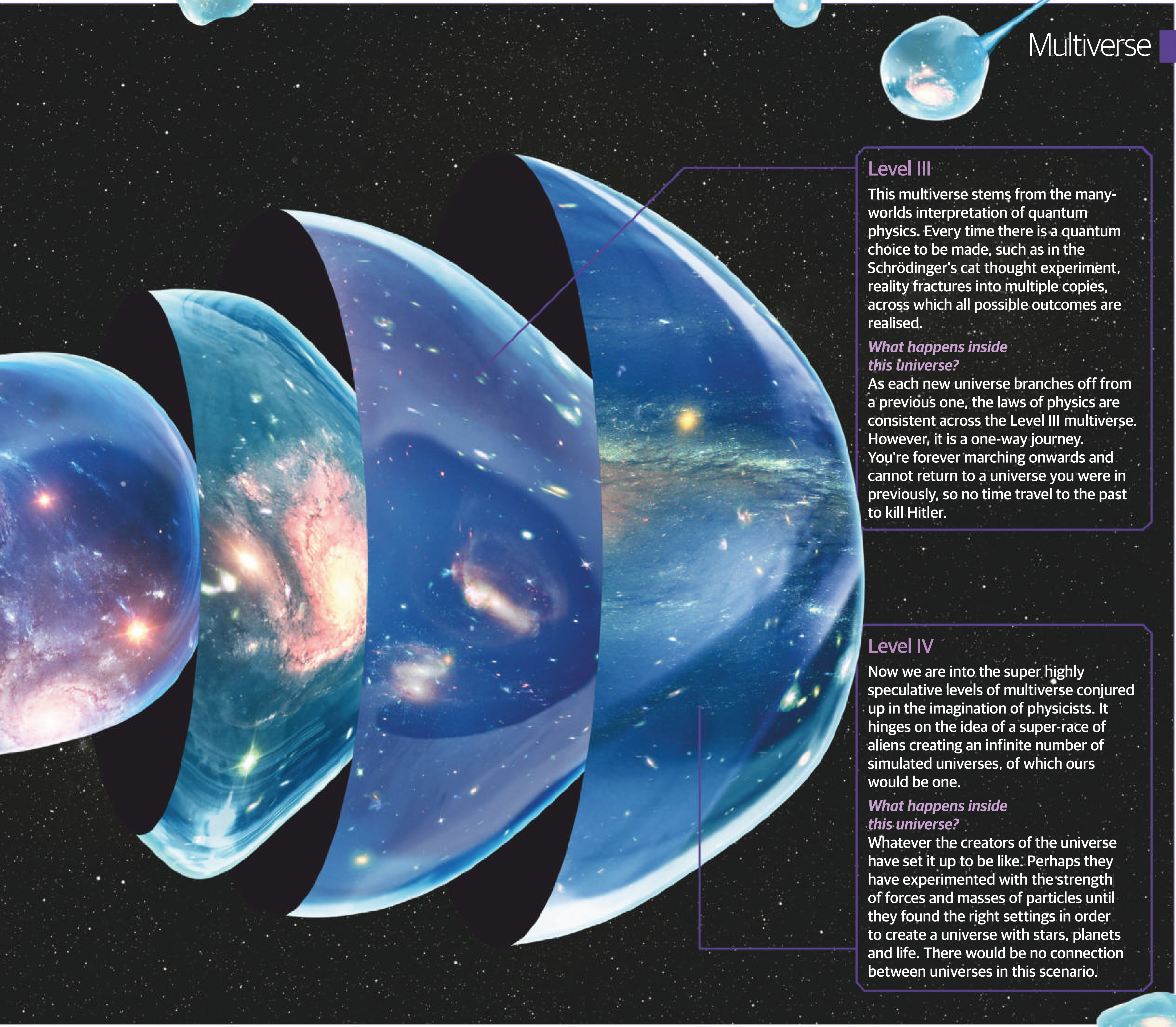
Left: The Schrödinger's cat thought experiment is one way to explore the possibility of other worlds

© Nicholas Forder

its mark on the sky. It's not an easy pill to swallow. "The idea left me uncomfortable, but we have to test it," says Shanks.

Unfortunately that's not an easy thing to do. The bubble collision theory should also have affected the orientation of the microwaves that make up the CMB. If we can measure this so-called 'polarisation' and it matches the predictions of inflation theory, it could be strong evidence in favour of the multiverse. Shanks put one of his students on the case, combing through data from the European Space Agency's Planck satellite, but that search was ultimately in vain. "Unfortunately Planck doesn't have the signal-to-noise ratio," says Shanks. The polarisation signal – if it's there at all – is so faint that Planck cannot distinguish it from the background noise of the cosmos and the probe's own instrumentation. It's a bit like trying to hear someone whisper when there is a pneumatic drill pounding away outside. One instrument that may be capable of picking it up is the six-metre (19.7-foot)



Level III

This multiverse stems from the many-worlds interpretation of quantum physics. Every time there is a quantum choice to be made, such as in the Schrödinger's cat thought experiment, reality fractures into multiple copies, across which all possible outcomes are realised.

What happens inside this universe?

As each new universe branches off from a previous one, the laws of physics are consistent across the Level III multiverse. However, it is a one-way journey. You're forever marching onwards and cannot return to a universe you were in previously, so no time travel to the past to kill Hitler.

Level IV

Now we are into the super highly speculative levels of multiverse conjured up in the imagination of physicists. It hinges on the idea of a super-race of aliens creating an infinite number of simulated universes, of which ours would be one.

What happens inside this universe?

Whatever the creators of the universe have set it up to be like. Perhaps they have experimented with the strength of forces and masses of particles until they found the right settings in order to create a universe with stars, planets and life. There would be no connection between universes in this scenario.

> "We have a lucky ticket and live in the universe that forms beautiful galaxies which permit life" **Jaime Salcido Negrete**

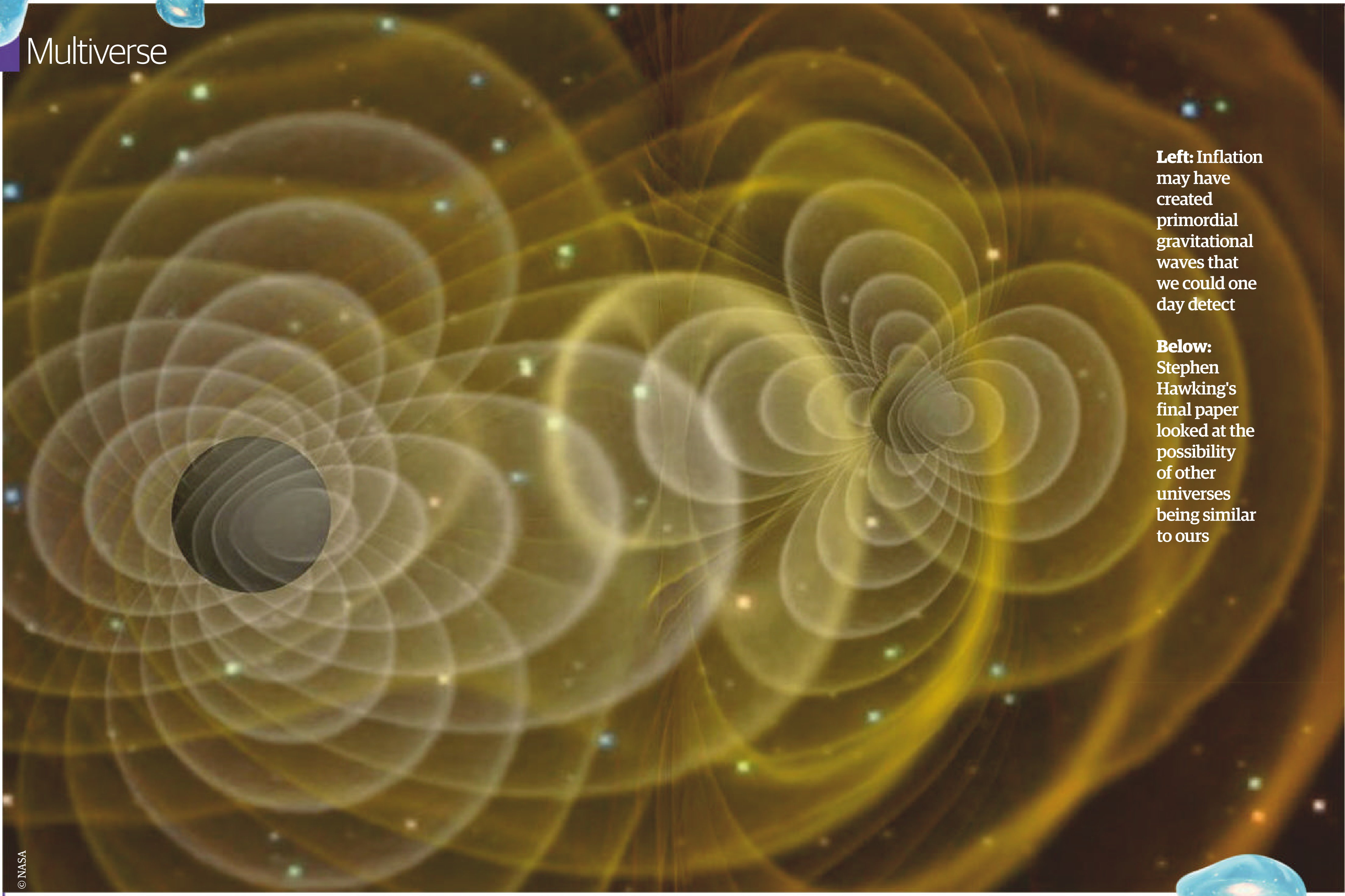
Atacama Cosmology Telescope in Chile, but it is yet to find that elusive signal.

Our reasonably new ability to pick up gravitational waves may do the trick. They are ripples in the very fabric of space itself, and the ones we've detected so far have come from colliding black holes and neutron star mergers. Yet the theory of inflation also predicts that events in the early universe should have generated so-called primordial gravitational waves. They would be tiny now nearly 14 billion years later, but future gravitational-wave detectors may be sensitive enough to spot them.

Equally, primordial gravitational waves passing through space when the CMB was released are predicted to have left their mark. Just like a bubble collision, they should have changed the orientation of some of the CMB microwaves. Back in March 2014 a result from the BICEP2 experiment in Antarctica made headlines around the world and generated much talk of an impending Nobel Prize. The team claimed to have found evidence of inflation - and a significant hint at other universes - in the CMB. Yet they'd jumped the gun. Further analysis showed that the same effect could have come from dust in our Milky Way galaxy.

Let's imagine for a moment that we do one day find irrefutable evidence that the cold spot in the CMB really is a bruise from a parallel universe and that the multiverse is real. How common would life be across this vast cosmic landscape? Not that rare according to work done last year by a collaboration of researchers from British and Australian universities. It all boils down to dark energy - the mysterious and invisible entity thought to be accelerating the expansion of our universe. The amount and strength of dark energy will be slightly different in each member of the multiverse.

If it's too strong then that universe will expand too quickly to ever allow gravity to gather material into stars and planets. Traditionally we've thought of our universe existing in a sweet spot where the amount and strength of dark energy is just right. "The multiverse theory could be thought of as a lottery. We have a lucky ticket and live in the universe that forms beautiful galaxies which permit life as we know it," says Jaime Salcido Negrete from Liverpool John Moores University.



Left: Inflation may have created primordial gravitational waves that we could one day detect

Below: Stephen Hawking's final paper looked at the possibility of other universes being similar to ours

© NASA

Yet stars and planets could still exist even if our universe had hundreds of times more dark energy or substantially less. At least that's according to state-of-the-art supercomputer simulations published in 2018 by Negrete and his team. "Adding dark energy up to a few hundred times the amount observed in our universe would actually have a modest impact upon star and planet formation," he says. The prospect of other universes with life in has had some big-name backers. Stephen Hawking's final scientific paper - published ten days before his death in 2018 - supported the notion that the laws of physics would be consistent across the multiverse. So what has happened in our universe could well have happened in others too.

That leaves us with a Level III multiverse, and for that we turn away from astronomy and towards quantum physics. The quantum world is famously weird. Unlike objects we encounter in our everyday lives, subatomic particles can exist in multiple places at once. Only once we measure the position of the particle does it 'decide' where it is. This is famously illustrated by the Schrödinger's cat thought experiment. The proverbial cat is in a sealed box with a vial of poison rigged to a hammer and a device to measure the position of a particle. If it is in position A then nothing happens. Yet if it's in position B the hammer is deployed, breaking the vial and killing the cat. The thing is, until the measurement is made the particle is simultaneously in position A and B. Meaning - at least in principle - the vial is broken and unbroken and the cat is both dead and alive at the same time.

> "Like the other forms of multiverse, the many-worlds theory is notoriously hard to prove"

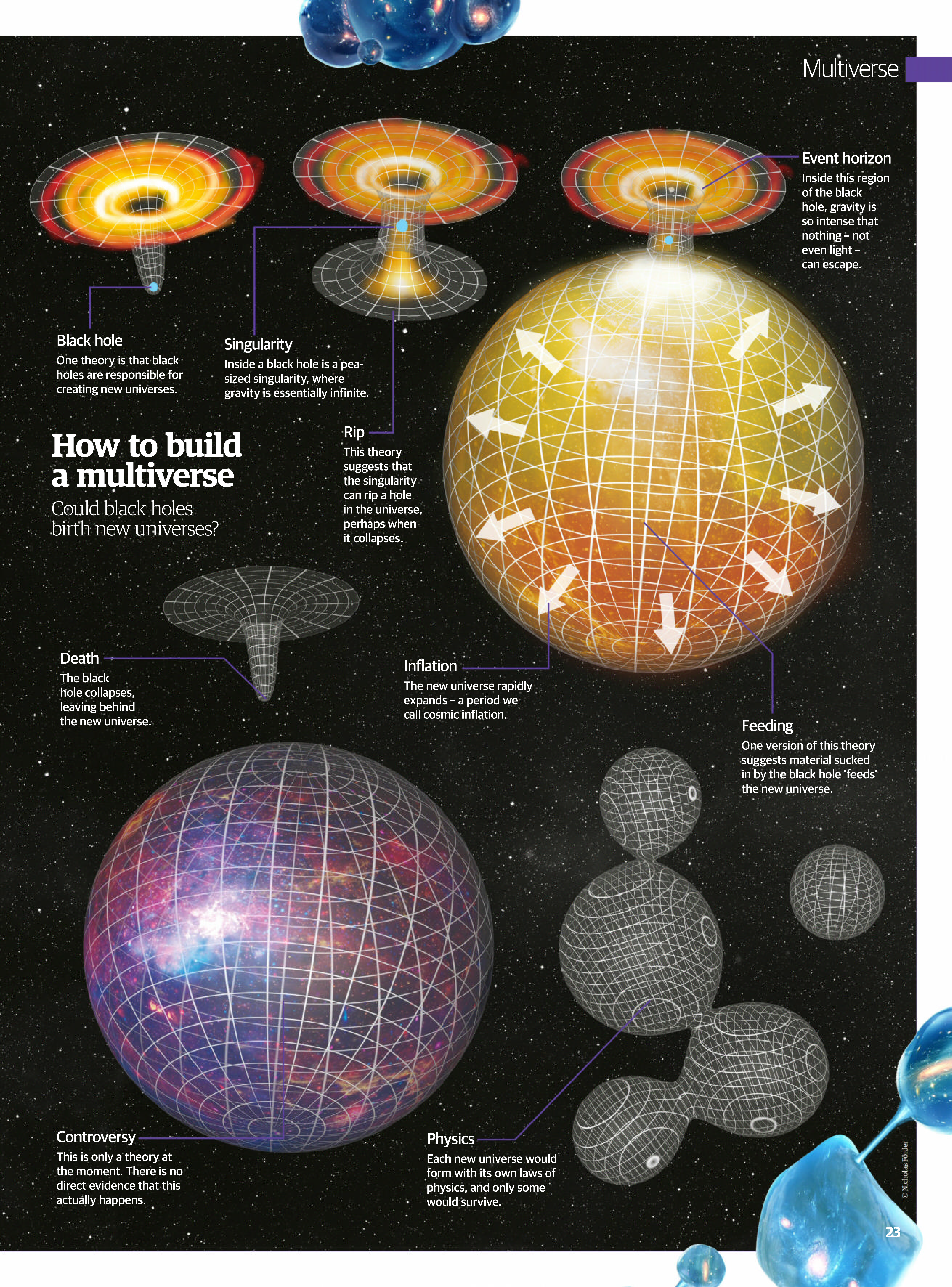
What leaves a lot of physicists uncomfortable is why the act of measuring forces the particle to 'choose'. An alternative explanation is that it doesn't choose at all. Whenever a quantum measurement is made the universe fractures into two realities - one with the particle in position A and another where it is in position B. This is known as the many-worlds interpretation. Like the pages of a book, these multiverses sit close together, but are separate from one another. There's no journeying between worlds. Like the other forms of multiverse, the many-worlds theory is notoriously hard to prove. It used to be a fringe theory on the sidelines of serious academic research, yet today it has quite a following.

There are those that rail against the multiverse, claiming it is little more than pseudo-science. Paul Steinhardt, one of the pioneers of the theory of inflation, has had a change of heart and is now an outspoken critic of those pursuing the existence other universes. But the draw is just too great, it fascinating to contemplate the notion that we are merely one of many copies of ourselves living lives both identical and different to our own. And, one day, if the theory of inflation is substantiated, it may just tell us how our own universe flashed into existence all those years ago.

Source: Wiki/ White House Photostream

How to build a multiverse

Could black holes birth new universes?



Black hole

One theory is that black holes are responsible for creating new universes.

Singularity

Inside a black hole is a pea-sized singularity, where gravity is essentially infinite.

Event horizon

Inside this region of the black hole, gravity is so intense that nothing – not even light – can escape.

Rip

This theory suggests that the singularity can rip a hole in the universe, perhaps when it collapses.

Inflation

The new universe rapidly expands – a period we call cosmic inflation.

Feeding

One version of this theory suggests material sucked in by the black hole 'feeds' the new universe.

Death

The black hole collapses, leaving behind the new universe.

Physics

Each new universe would form with its own laws of physics, and only some would survive.

Controversy

This is only a theory at the moment. There is no direct evidence that this actually happens.

© Nicholas Forder

INSIDE A MARTIAN HABITAT

What are humans going to live in once they're on Mars? One New York company thinks it has the answer

Earlier this autumn, **space.com** visited the main offices of AI SpaceFactory, an architecture and technology design agency that specialises in designing and 3D-printing Martian habitats. The company recently competed in and won NASA's 3D-printed habitat challenge with a design called Marsha. AI SpaceFactory founder and CEO David Malott took **space.com** around this space factory to see what it really takes to build a Martian habitat.

"The whole reason to do that is, it's too expensive to ship materials to Mars," Malott said to **space.com**. "We want a place for the astronauts to stay in," he added. When we are ready to send humans to live on the surface of Mars, they will need somewhere to live. But construction equipment and materials are large and heavy, and it would be both difficult and extremely expensive to send them to another planet. Buildings on Mars have "to be made robotically in advance of the astronauts arriving using materials made from Mars," Malott added.

The material that the company uses for its Martian printing is, in fact, 'made from Mars', in a way. "It's a biopolymer binder with basalt," Malott said. "Basalt is the rock that you find all over Mars." While all of the ingredients in the company's printing mixture come from our home planet, they are materials that can also be found on Mars.

"The good thing with local Martian materials is they're also local on Earth," he said. The pieces of Marsha scattered around the facility that we picked up and held even felt alien: extremely sturdy, intricately layered and woven, kind of slippery and overall unique.

It turns out that printing a habitat with this material is very sensitive to temperature, so the team at AI SpaceFactory monitors the process very closely. "I compare this to cooking eggs," Malott said. "It's all about timing and temperature, and that's why we are forcing ourselves to print Tera, and we're printing Tera completely outdoors," he added about Tera, the new Earth habitat the company is working on.

But the careful 'cooking' is worth it: the material is not only extremely strong – a major part in how Marsha won the NASA competition – but also "100 per cent recyclable," Malott said. To validate its recyclability, the team even ground up material from Marsha to use to print Tera.

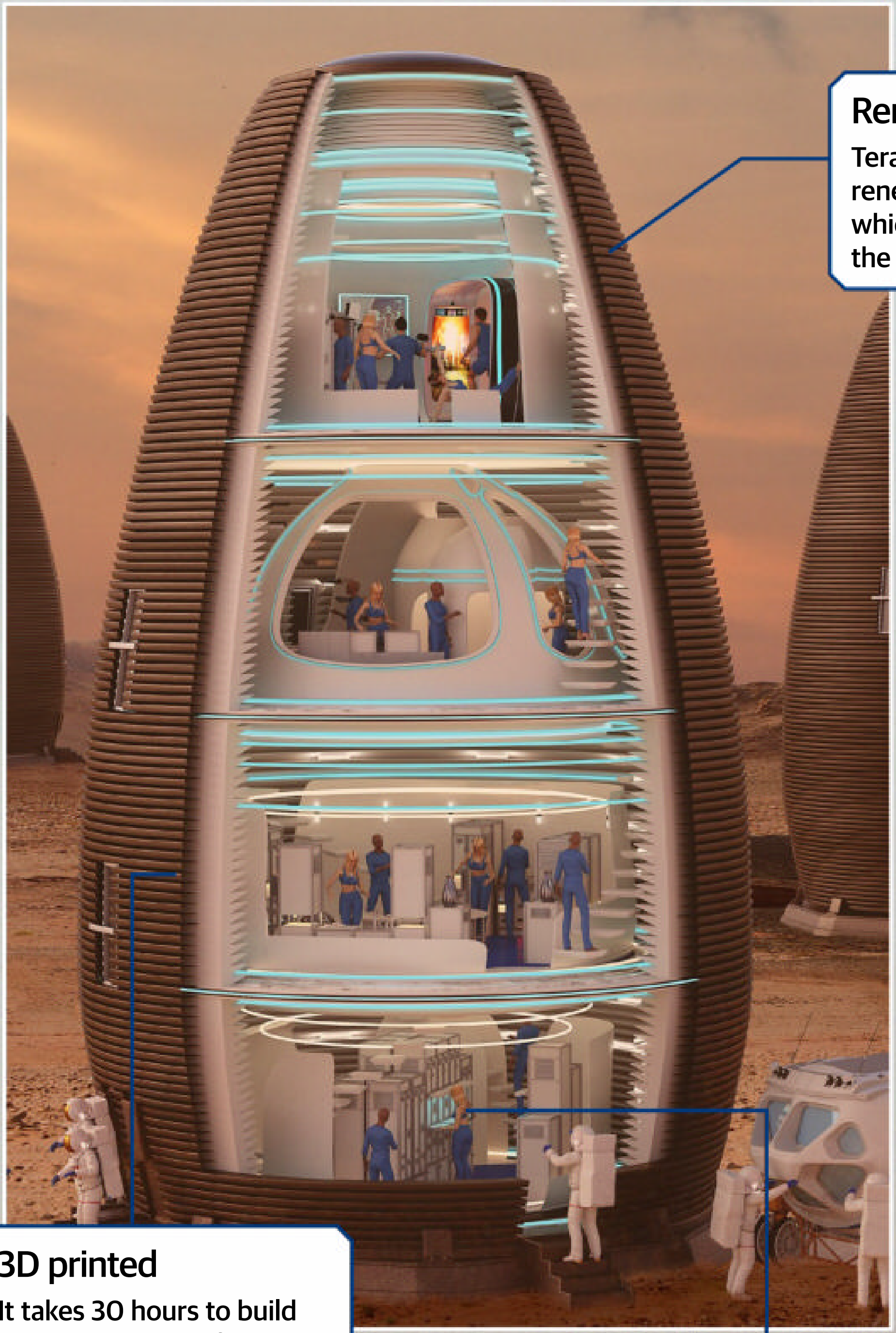
Besides being strong and recyclable, this Martian printing material is also more resource efficient than cement and concrete, which are used in a majority of building projects on Earth. Unlike cement and concrete, which also aren't recyclable, the material's production doesn't require the use of water or large amounts of energy.

Malott also described some ways in which this Martian 3D-printing technology could be applied here on Earth. "One of the challenges on Earth is building in places, say, like the Bahamas, which recently got obliterated by a hurricane," he said. "If you need to go somewhere fairly remote where the infrastructure's just been destroyed, and you have to produce a lot of housing, how do you do that?

"The whole wonder of what we're doing is that, by thinking about the challenge of how to build in an extreme and remote environment on Mars, we're actually solving a fundamental challenge about building on Earth, which is building in a more sustainable way," Malott said.

The habitat would be home to future generations

Labratories, hospitals and amenities would be included



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Renewable shell

Tera's exterior shell is both renewable and recyclable, which minimises impact on the environment.

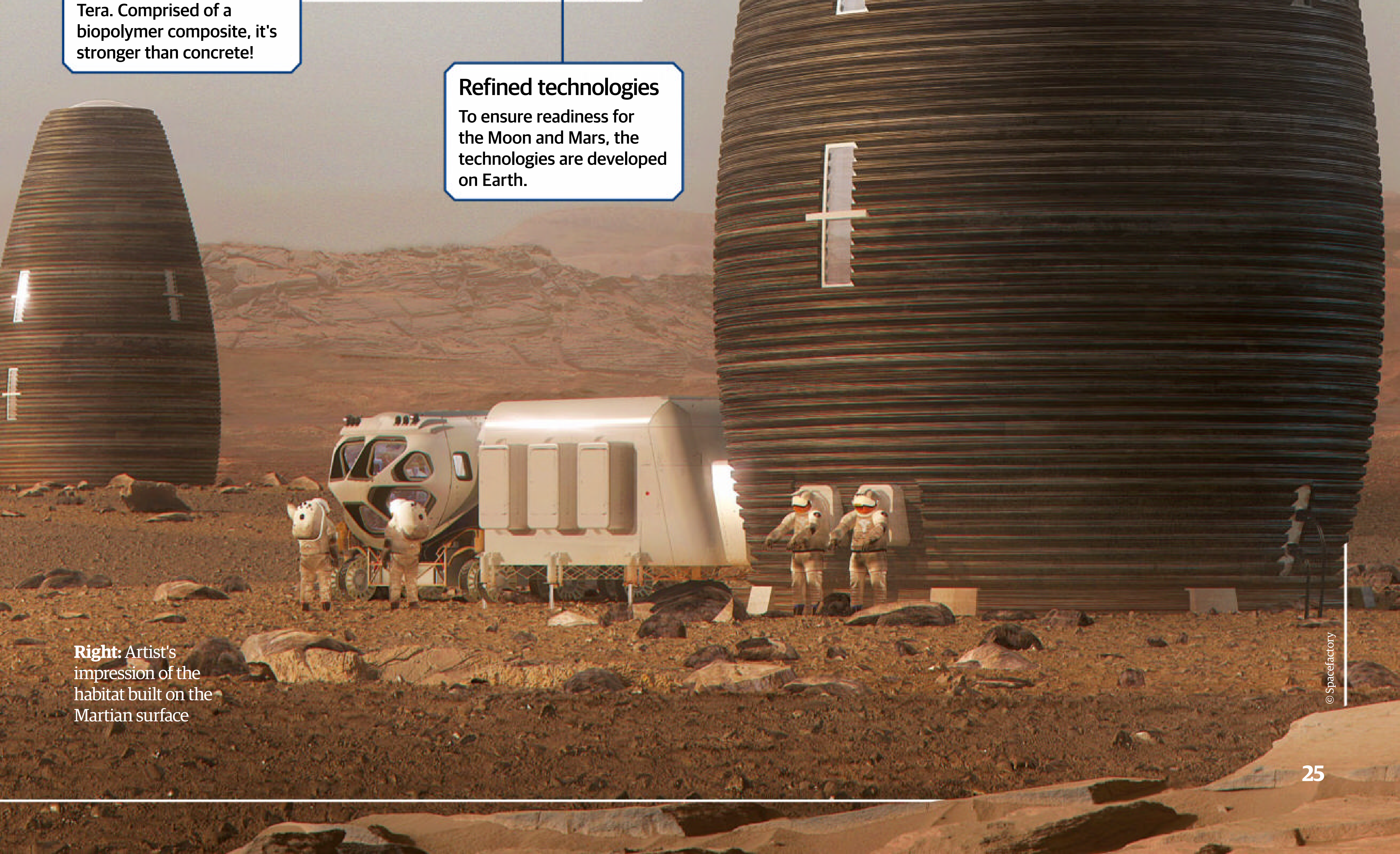
3D printed

It takes 30 hours to build Tera. Comprised of a biopolymer composite, it's stronger than concrete!

Refined technologies

To ensure readiness for the Moon and Mars, the technologies are developed on Earth.

> "It's too expensive to ship materials to Mars"
>
> **David Malott**



Right: Artist's impression of the habitat built on the Martian surface

© Spacefactory

MYSTERIES OF THE UNIVERSE

DOES COMET BORISOV HAVE ALIEN ORIGINS?

A second interstellar interloper has been discovered within the Solar System, but it won't be hanging around

Reported by David Crookes

Some mysteries have been perplexing astronomers for some time, while others have arrived on the scene only recently. In the case of the Solar System's newest guest, the latter is most certainly true. It was 30 August 2019 when amateur astronomer Gennadiy Borisov pointed his telescope skywards in Crimea, and what he saw that night not only amazed him, but sent fellow scientists scurrying for a look.

Borisov's observation was extraordinary. "It was the most exciting discovery of 2019," exclaims Paul Kalas, adjunct professor of astronomy at the University of California, Berkeley. What he discovered that night, it transpired, was an interstellar comet which has become known as Comet 2I/Borisov. But exactly where it came from and what it tells us about

© Tobias Roetsch

Comet Borisov by the numbers

2019

Year Comet Borisov was discovered

300,000,000

Number of kilometres Borisov will be from our Sun at its closest approach (that's 2AU, so twice the distance from Earth to the Sun)

3.3

The value of 2I/Borisov's heliocentric orbital eccentricity

19

Kilograms of water being lost each second

16

Largest predicted size of 2I/Borisov's nucleus in kilometres

0.5

Smallest predicted size of 2I/Borisov's nucleus in kilometres

10%

Chance that the comet will disintegrate

9,000

Number of years to travel a light year relative to the Sun

our universe is now the subject of much study as astronomers around the world seek answers.

Interstellar visitors are rarely discovered. In fact, in the whole of space history we have only ever seen one before - the odd, cigar-shaped 'Oumuamua, which made its closest approach to Earth in October 2017. Comet Borisov's trajectory was such that astronomers could tell it had come from outside the Solar System. As you may expect, this led to some wild speculation.

"We can't rule out that this is an interstellar probe," claimed Dr Seth Shostak, a senior astronomer at the SETI Institute in California, shortly after the discovery, hinting at an alien origin. And yet further analysis says we can. "It looks like a comet. It acts like a comet. It is clearly not orbiting the Sun," says Max Mutchler, a research and instrument scientist from the Space Telescope Science Institute in Baltimore. "So until there is evidence of anything else, it is a comet."

Not that this makes it any less interesting. The same speculations about alien craft were raised following the discovery of 'Oumuamua, and while they have since been dispelled, it remains a fascinating object. "An interstellar comet is plenty exciting without anyone heaping wild speculation on top of it," Mutchler tells us. To that end, much of the work is focused on tracing Borisov's trajectory and discovering its composition as a comet. Time, however, is of the essence. Since the comet is now travelling at 177,028 kilometres (110,000 miles) per hour, studies have to be fast. One thing's for sure, Comet 2I/Borisov's visit to the Solar System is going to be fleeting.

So what do we know so far? Well, it would appear that the comet is more ordinary than first imagined. According to astronomers working across Europe, Borisov closely resembles comets that have originated within the Solar System - those which come from the Kuiper Belt in the region inhabited by Pluto or those from the Oort Cloud of icy objects situated a light year from our Sun.

Indeed, like home-grown comets Borisov has a reddish, carbon-rich surface, and it also produces some 170 grams of cyanide gas every second, caused by sunlight warming the ice that has formed across the comet. Further research suggests that the core beneath its halo of dust and gas could be anywhere between 1.4 to 6.6 kilometres (0.9 to 4.1 miles) across - again, not uncommon.

Even so, it is different to the previous interstellar interloper. "It has the features of a comet - a coma and a tail of dust - which require an ice-rich composition combined with strong heating as it approaches a star, whereas 'Oumuamua didn't show any comet-like features," Kalas tells us of the fundamental difference.

"It's thought 'Oumuamua was probably like many other asteroids and Kuiper Belt objects in our Solar System, except that it was not gravitationally bound to our Sun." Having two different types of object come in from outside the Solar System, however, makes the discovery of Comet 2I/Borisov extra exciting.

Astronomers are certainly fortunate to have spotted the interstellar comet on its approach to Earth rather than when it was already here, as with 'Oumuamua. Indeed, Borisov is due to pass about 306 million kilometres (190 million miles) from our planet in December 2019, according to NASA, and it's not due to leave until mid-2020. That's a huge amount of time in which astronomers can carry out their studies. Hubble is among the instruments being used for observations.

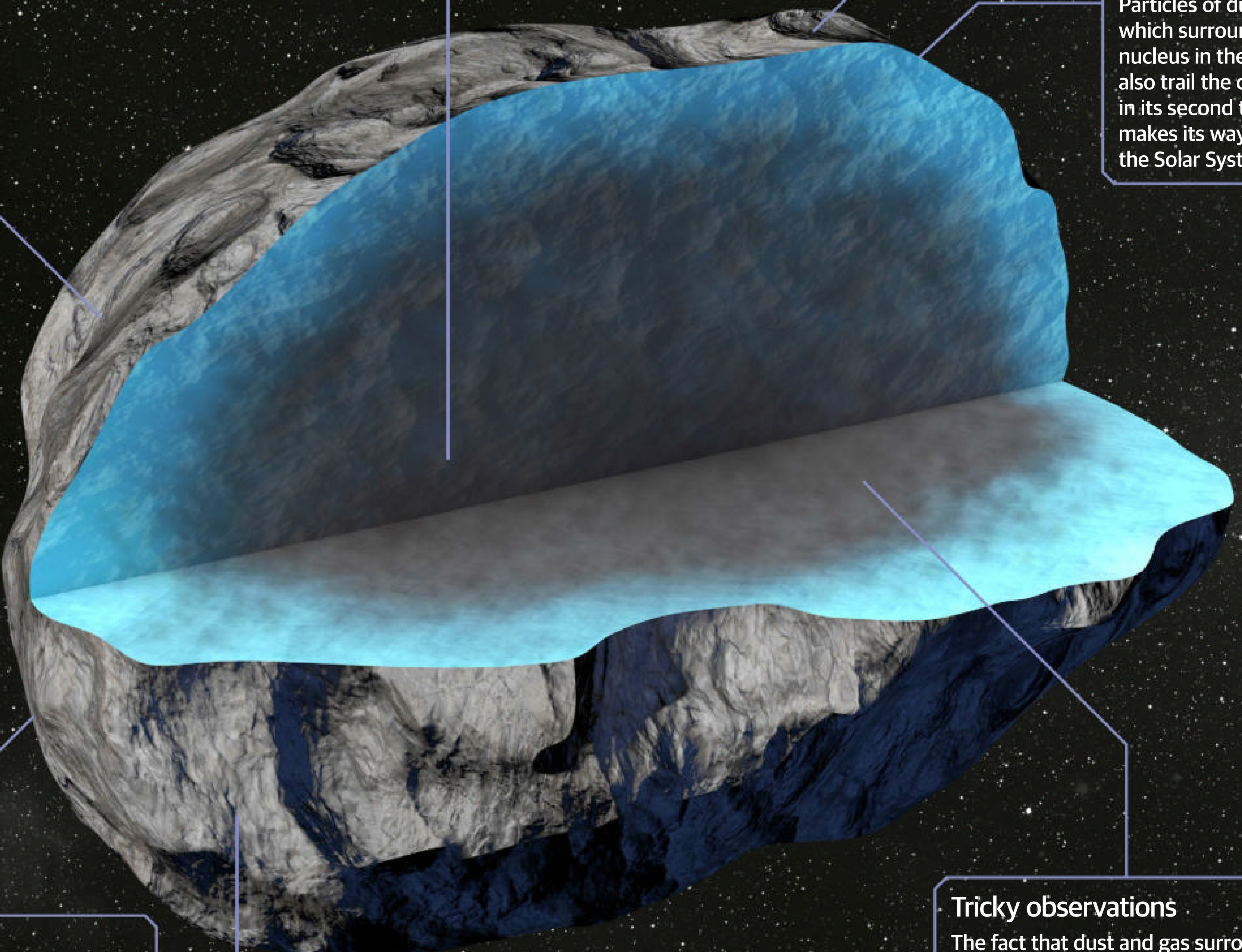
"The beautiful images we saw in October were the first observations made with the Hubble Space Telescope, and it delivers exquisite sharpness," says Kalas. "With this data we can see that the coma [the dust surrounding the nucleus of the comet] has an hourglass shape, which has also been found in

Below: 'Oumuamua was the first interstellar object to be discovered, back in 2017

© ESA

The structure of Comet Borisov

If it was possible to slice through the interloper, what would be found within?



Borisov's coma

The presence of a well-defined extended coma made of ice and dust was immediately observed, which is why 2I/Borisov was classified as a comet. Cyanide gas and diatomic carbon were detected, which are not uncommon.

The comet's heart

At the centre of 2I/Borisov's coma is the solid nucleus, which astronomers say is between 1.4 and 6.6 kilometres (0.9 to 4.1 miles) in diameter. Its shape doesn't appear to set it apart from comets that have originated within the Solar System.

Short tail

2I/Borisov appears to have a short but toxic tail because of the gas being produced by the cyanide compounds. The production rate of this commonly produced gas is 170 grams per second, which is little different to that of other comets.

Dust particles

Particles of dust which surround the nucleus in the coma also trail the comet in its second tail as it makes its way across the Solar System.

Warming up

2I/Borisov is said to have become active when it was about 4AU from the Sun in June 2019. It is the sunlight which warms the icy surface of the comet.

Tricky observations

The fact that dust and gas surround the nucleus makes it difficult to figure the exact centre of the comet, but eyes will be on Borisov for months to come and more discoveries will be made.

Colourful mover

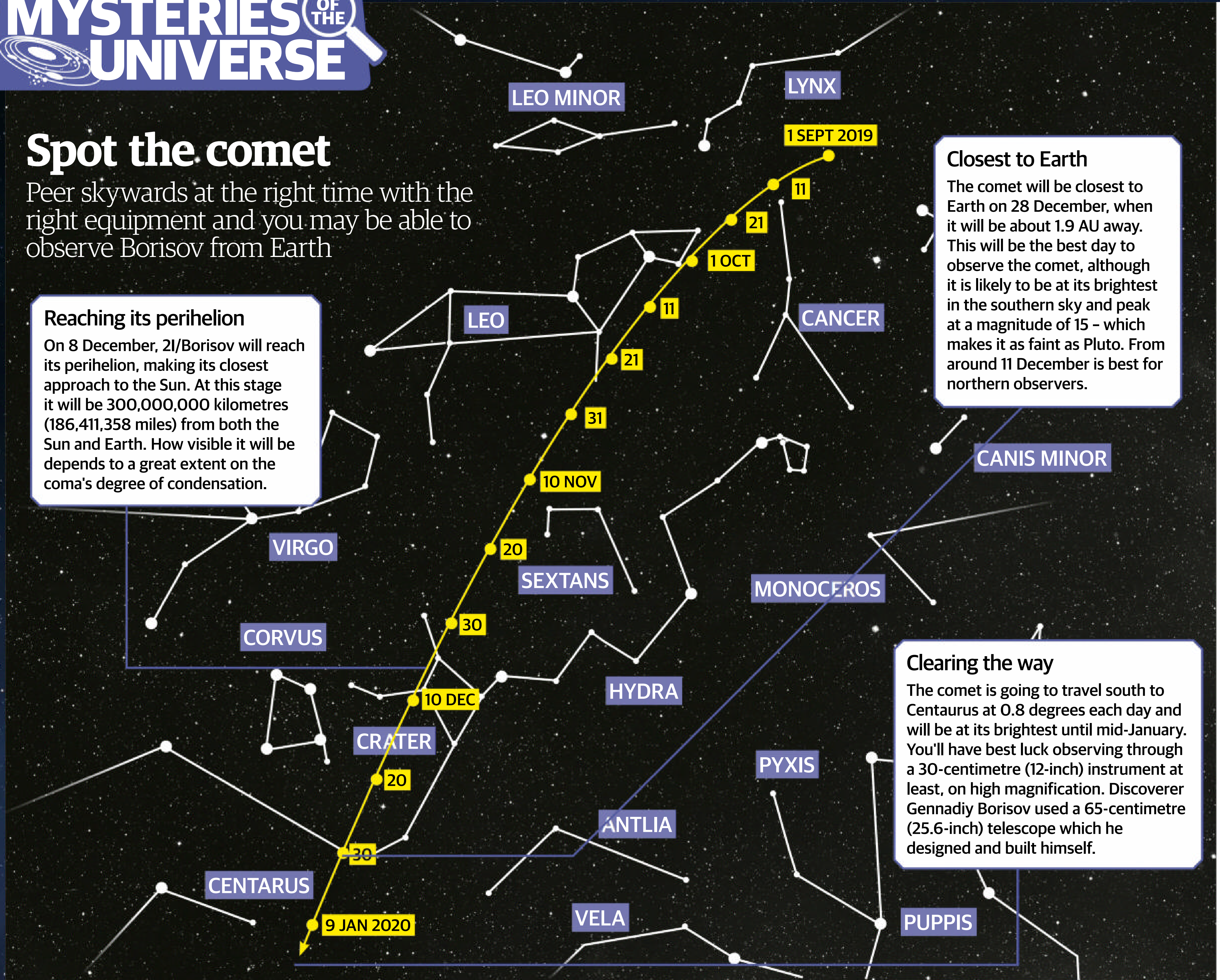
Observations have measured a slightly reddish colour on the carbon-rich surface of 2I/Borisov, consistent with Solar System comets, as it travels at over 155,000 kilometres (96,313 miles) per hour.

> "It has the features of a comet – a coma and a tail of dust – which require an ice-rich composition"
>
> **Paul Kalas**

© Adrian Mann

Spot the comet

Peer skywards at the right time with the right equipment and you may be able to observe Borisov from Earth



Reaching its perihelion

On 8 December, 2I/Borisov will reach its perihelion, making its closest approach to the Sun. At this stage it will be 300,000,000 kilometres (186,411,358 miles) from both the Sun and Earth. How visible it will be depends to a great extent on the coma's degree of condensation.

Closest to Earth

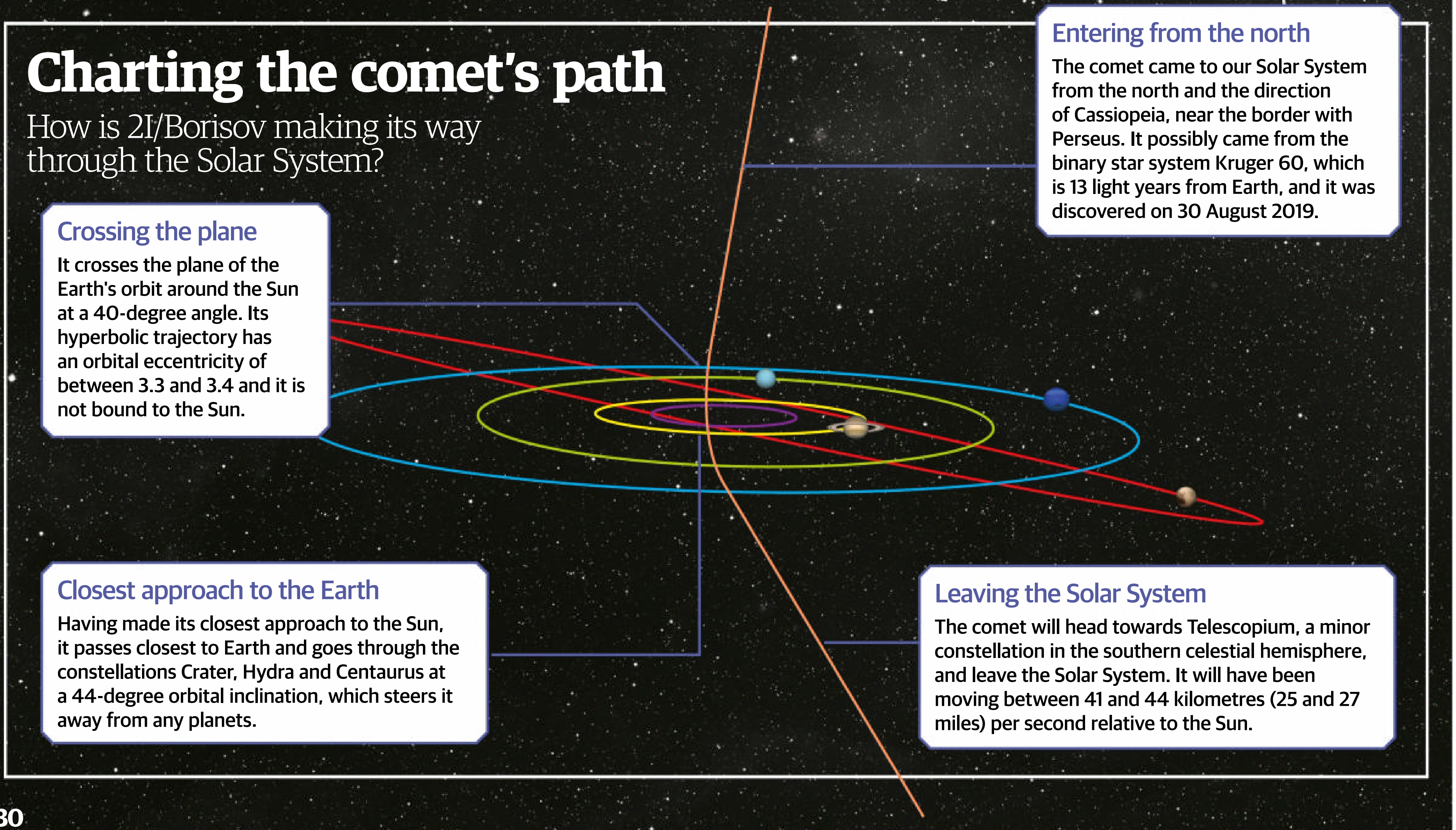
The comet will be closest to Earth on 28 December, when it will be about 1.9 AU away. This will be the best day to observe the comet, although it is likely to be at its brightest in the southern sky and peak at a magnitude of 15 – which makes it as faint as Pluto. From around 11 December is best for northern observers.

Clearing the way

The comet is going to travel south to Centaurus at 0.8 degrees each day and will be at its brightest until mid-January. You'll have best luck observing through a 30-centimetre (12-inch) instrument at least, on high magnification. Discoverer Gennadiy Borisov used a 65-centimetre (25.6-inch) telescope which he designed and built himself.

Charting the comet's path

How is 2I/Borisov making its way through the Solar System?



Entering from the north

The comet came to our Solar System from the north and the direction of Cassiopeia, near the border with Perseus. It possibly came from the binary star system Kruger 60, which is 13 light years from Earth, and it was discovered on 30 August 2019.

Crossing the plane

It crosses the plane of the Earth's orbit around the Sun at a 40-degree angle. Its hyperbolic trajectory has an orbital eccentricity of between 3.3 and 3.4 and it is not bound to the Sun.

Closest approach to the Earth

Having made its closest approach to the Sun, it passes closest to Earth and goes through the constellations Crater, Hydra and Centaurus at a 44-degree orbital inclination, which steers it away from any planets.

Leaving the Solar System

The comet will head towards Telescopium, a minor constellation in the southern celestial hemisphere, and leave the Solar System. It will have been moving between 41 and 44 kilometres (25 and 27 miles) per second relative to the Sun.

Solar System comets as they approach the Sun. Future observations may discover jets of gas shooting out in specific directions from the nucleus, but a particularly exciting possibility is that the nucleus will break apart into many fragments."

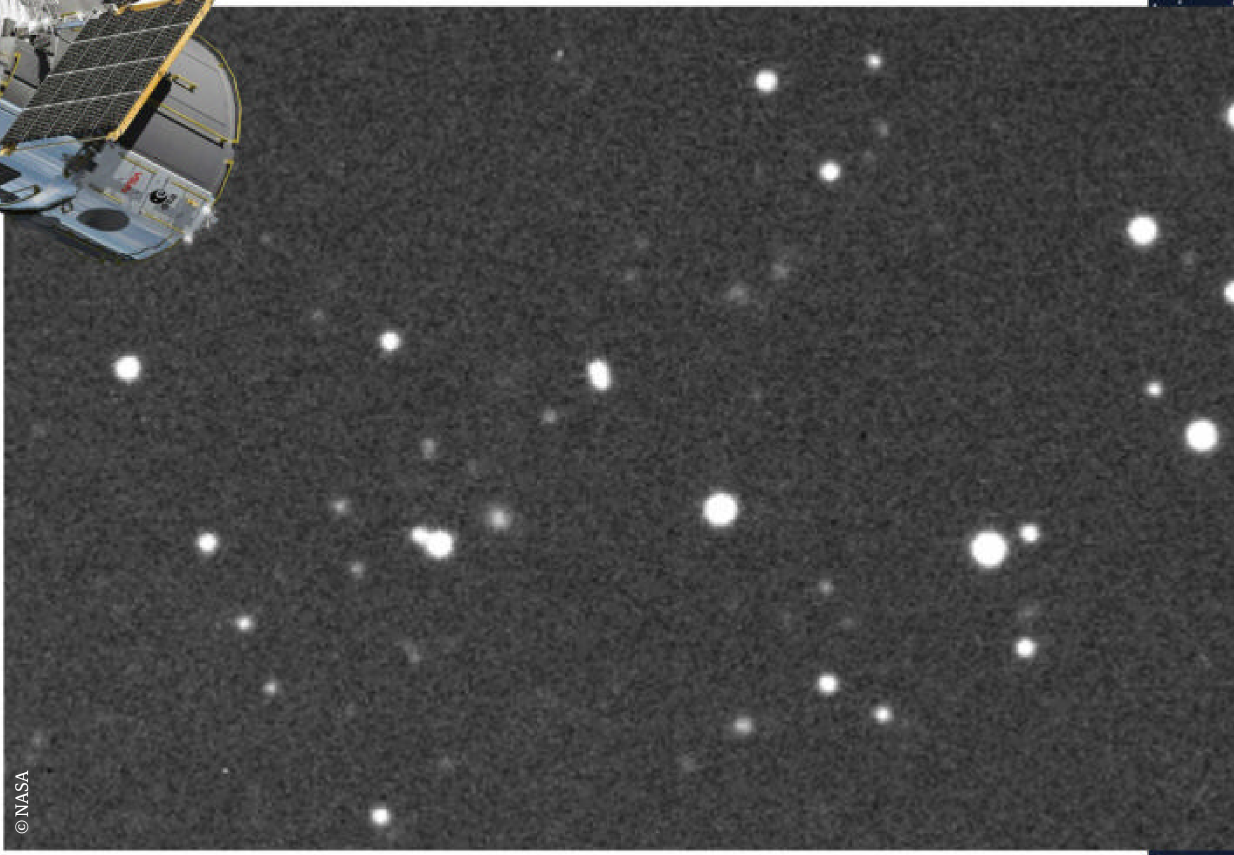
The chances of the latter happening are as low as ten per cent, but that is still high enough. In the meantime, and ahead of such a possible fate, data from Hubble is being combined with that collated on the ground, and the hope is that scientists will get a better estimate of the shape and size of the nucleus. Measurements across different wavelengths will also tell researchers what the comet is made of. Meanwhile, Kalas has a student at Berkeley working on the potential trajectory of the comet, but it'll be a while before we have conclusive answers.

"The comet isn't interacting much with our Solar System," affirms Mutchler. "The Sun's gravity is barely modifying its course and it doesn't get near any planets. The orbital path is interesting in that it gives a hint of where the object may have come from, but that is a difficult task which relies on a few assumptions."

Nevertheless, some studies have already worked on giving a set of clues. Polish researchers believe Comet 2I/Borisov's path leads back to a binary red dwarf star system called Kruger 60, which is 13.14 light years from the Sun. The study also suggested that the comet passed 5.7 light years from the centre of Kruger 60 a million years ago, travelling at 12,348 kilometres (7,670 miles) per hour.

Such a small relative velocity of the two objects during this approach was, they concluded, not indicative of the comet merely passing by. Rather it most likely originated from that star system, they said, although the findings are not confirmed.

One of the difficulties in studying the comet is the trickiness of getting decent data. It's not easy to pinpoint the core of an object that, when imaging through a telescope, is blurred. More than that, determining the origin of an interstellar comet entails figuring out the position of the Milky Way's stars in the required timeframe when we don't yet have a full star map of the galaxy. What we do know is that it has an extremely hyperbolic orbit, which points to its interstellar status as opposed to an elliptical orbit typical of 'domestic' comets.



© NASA

Right: An image taken by Gennadiy Borisov - using equipment he made himself in Crimea - showing the comet

We do have great photographs, though. The first colour image was snapped on the night of 9-10 September using the Gemini Multi-Object Spectrograph on the Gemini North Telescope that's on Mauna Kea in Hawaii. It clearly showed the aforementioned pronounced comet tail. Yet getting that photo was no easy task. "We really had to scramble for this one, since we got the final details at 03:00 and were observing it by 04:45," says Andrew Stephens, who works at the observatory.

He also explained the image was possible because of Gemini's ability to rapidly adjust observations and observe objects such as Comet 2I/Borisov with its very short window of visibility. Meanwhile, Hubble began observing the comet on 12 October when it was 418 million kilometres (260 million miles) from Earth. It will continue doing so as it makes its way through the Solar System and presumably leaves in the direction of the constellation of Telescopium. But what other mysteries will it help to uncover as it does so?

One of the key reasons why this comet is so intriguing is because of its potential to explain how

The theories

There are various explanations for what it could be - and where it's come from

A home-grown comet

When Gennadiy Borisov first discovered the object on 30 August 2019, it was thought to have been born within our Solar System. Perceived to be a near-Earth object, it was given the designation gb00234 by the International Astronomical Union's Minor Planet Center and was later noted to be a comet, designated C/2019 Q4 (Borisov).

© NASA

An interstellar interloper

Within two weeks scientists were already suspecting it was a comet from outside of our Solar System, even though it's similar to those born within. By 24 September 2019 the International Astronomical Union had given it the interstellar designation 2I/Borisov - following on from 1I/'Oumuamua. This remains the most accepted explanation.

© ESO

An alien probe

Even so, after hearing about the discovery of the interstellar interloper, Seth Shostak, senior astronomer for the SETI Institute, said: "We can't rule out that this is an interstellar probe." He said a closer look may reveal a metal surface and alien faces staring out of portholes. However, he then went on to bet money that it was simply a comet.

© Pixabay

It has travelled 13 light years

With the smart money on an interstellar comet, the task has been to clear up the mystery of where it has come from. This remains a subject of study, but the theory that it originated from a binary red dwarf star system called Kruger 60, some 13.14 light years from the Sun, is a strong one. All eyes will be on this visitor for some months to come.

© NASA, ESA

comets and other objects from outside of the Solar System. This in turn can shed better light on the origins of objects closer to home.

"We don't know exactly how planets form in our own Solar System or elsewhere," says Mutchler. "So it is interesting that this comet seems similar to comets in our own Solar System, since they are one of the building blocks for planets. It hints that perhaps the planet-building process is similar in other star systems, but again we'd like to see many more examples before concluding anything."

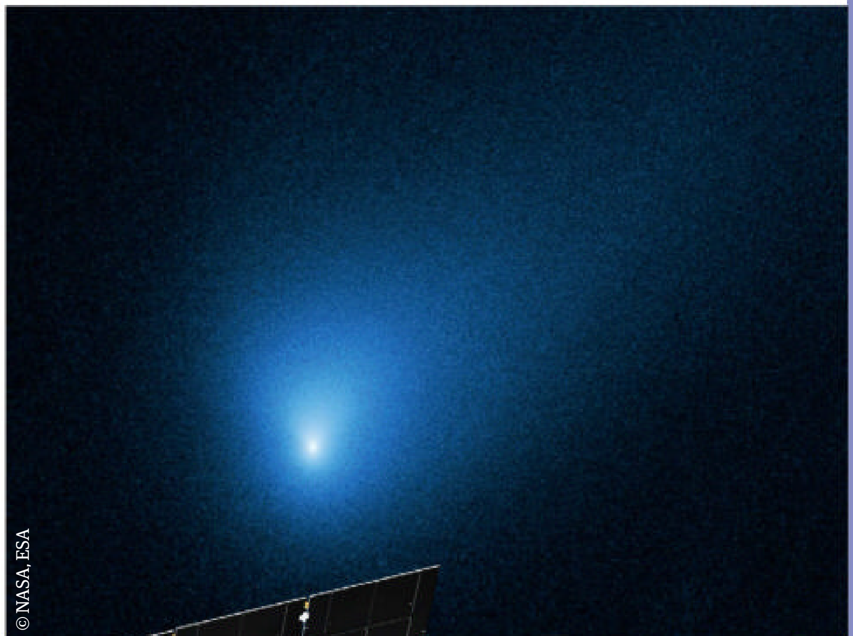
The very fact that we now have two different interstellar objects to study is certainly pleasing scientists, but it has also thrown up a mystery of its own. "It's a puzzle why these two are so different," says David C. Jewitt of the University of California, Los Angeles, leader of the Hubble team who observed the comet.

"They likely have different origins and history, so they would each tell a different story," enthuses Mutchler. "But they are just two objects representing trillions of objects that have likely been ejected by their parent stars into interstellar space, so we can't even assume that these two reflect the majority very well. We'll need to discover and study thousands more before we start to get a balanced idea of what is out there."

The expectation is that we will see more interstellar objects very soon. After all, we have now been able to gather observations and evidence of two in two years. "Advances in technology are allowing astronomers to monitor the entire sky for transient events such as interstellar comets that zip through our Solar System very quickly and unpredictably," explains Kalas. "Amateur astronomers like Borisov are also able to use their own equipment, which is becoming ever more sophisticated." Borisov used a 0.65-metre telescope that he designed and built himself, which makes the discovery even more remarkable.

It cements the fact that with effort, talent and the right gear, any amateur astronomer could survey the night sky for other mysterious interstellar objects, although a good number of them are beyond the capabilities of modern-day telescopes. Still, it won't stop the search, especially when two diverse objects have been seen so far.

"Nobody knows how many there are out there in interstellar space, but planet-formation models imply that most of the small objects would get ejected as planets form and migrate," says Mutchler. "There should be many more 'rogue' comets and asteroids than the ones still orbiting their parent star, but they are spread out in the enormous volume of space between stars, so are understandably rare. We have more sky surveys underway and planned though, which should discover many more asteroids and comets in our own Solar System. More interstellar visitors are expected."



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Above: This sharp image of 2I/Borisov was taken by NASA's Hubble Space Telescope in October 2019

Right: ESA's Comet Interceptor mission will help us to understand these visitors to our Solar System

Quickfire questions

Has the discovery of interstellar objects been surprising?

No. Scientists have anticipated such objects for a long time because it is understood that our Solar System once had many more asteroids and comets than today. The majority were ejected into interstellar space through encounters with Jupiter, and astronomers have long believed this has been the case with other planetary systems.

So a comet has been expected?

Yes. If anything the discovery of the first interstellar object, 1I/'Oumuamua, was the odd one. Astronomers had expected a comet to pay the Solar System a visit, as we are seeing now, so when an asteroid was observed first – particularly a cigar-shaped one that was unlike anything else seen – it certainly caught science off guard.

What are we learning about our Solar System?

Given that 2I/Borisov appears to be very similar to regular comets in our Solar System, the key takeaway is that the Solar System is not quite so unique. It shows that other parts of the universe can be seen to form in the same way, and this could point to a greater potential for life to exist elsewhere.

Could the comet itself be harbouring life?

It is unlikely. What we are aware of, however, is a study which says 2I/Borisov is harbouring water from another star system, and that's very exciting. Again it goes back to showing the comets in our Solar System are not unique, and it's also the first time alien water has been detected so close.

If we know so much, why is it a mystery?

Precisely because we don't know that much. The comet's trajectory and its origins are a mathematical theory based on the small amount of data we have ahead of where it's been so far. Likewise, its size is unknown because as well as the actual object, we're also seeing its tail, which blurs things somewhat. There had been hope we could fly a spacecraft to it – but the European Space Agency's Comet Interceptor is not yet ready.

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INTRODUCING THE NEXT-GENERATION SPACESUIT

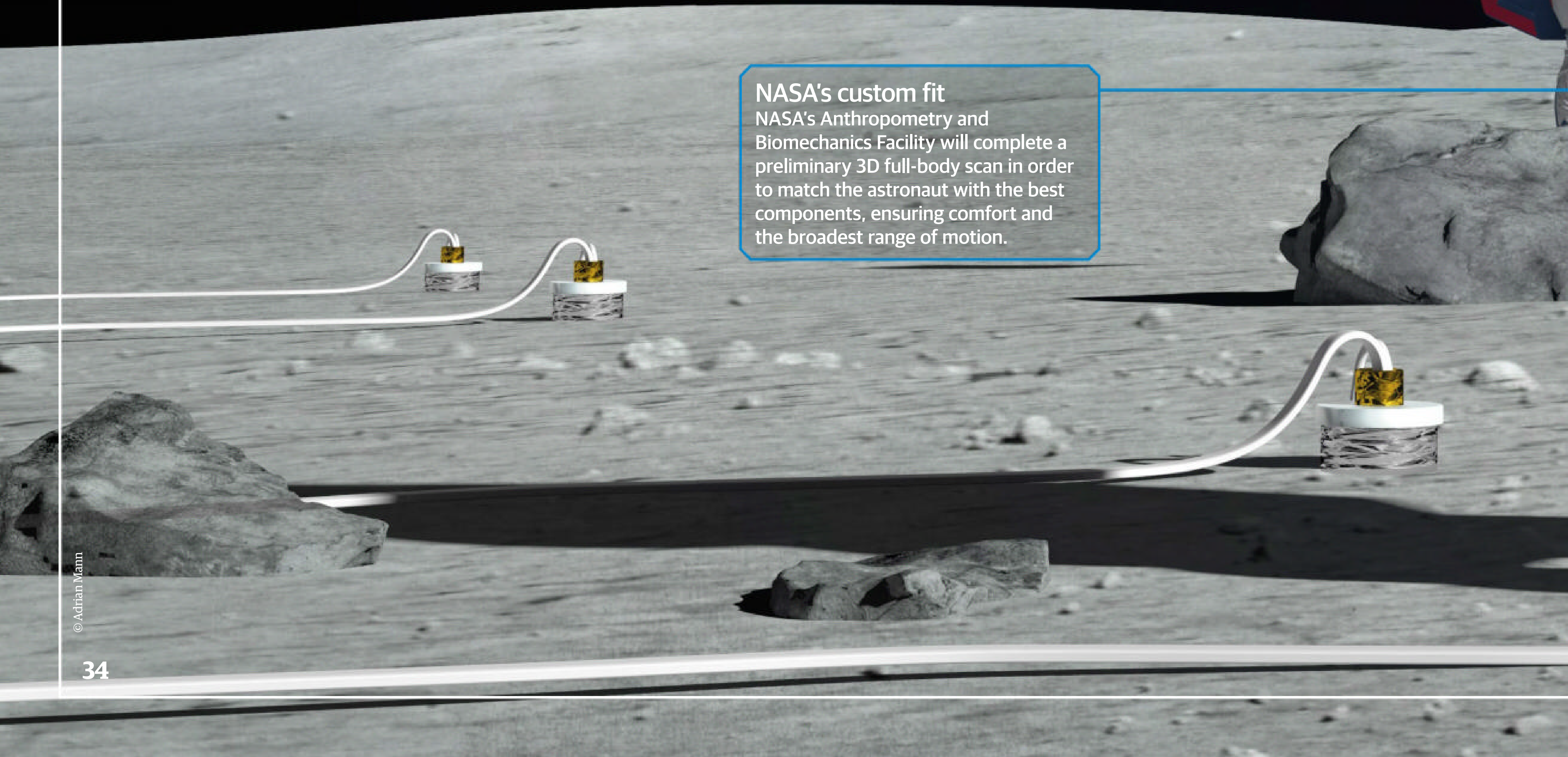
Under NASA's Artemis program, the agency has revealed its new attire for future exploration missions

NASA's spacesuits have seen a gradual evolution over the years. First were the original tin-foil spacesuits of the Mercury program, which were improved versions of the US Navy's high-altitude flight suits. Currently in use are the huge mechanical suits that astronauts take hours to put on before a spacewalk outside the International Space Station (ISS). NASA is now building up steam ahead of its Artemis program, which will put a man or woman on the lunar south pole by 2024. With this aim in mind the agency has announced a new spacesuit with the Exploration Extravehicular Mobility Unit, or xEMU for short.

Ultimately the spacesuit is there to keep the astronaut safe from the dangers of space. Hazards from the external environment include extreme temperatures, radiation, micrometeoroids and reduced atmospheric pressure. The spacesuit will first and foremost address these issues, but also something that wasn't prepared for ahead of the Apollo missions: lunar soil. Apollo astronauts discovered that lunar soil is essentially tiny glass-like shards that stuck to their suits and became a real nuisance. To make this less of a problem, the xEMUs have dust-tolerant features to avoid inhalation and contamination. The new suit also protects against extreme temperatures, holding its own at temperatures as low as minus 157 degrees Celsius (minus 250 degrees Fahrenheit) and as high as 121 degrees Celsius (250 degrees Fahrenheit).

The xEMU's Portable Life Support System is the hub of the suit: it filters out carbon dioxide and other harmful gases while replenishing the supply of breathable oxygen and regulating the temperature. Improvements in electronics and plumbing systems have allowed engineers to replicate much of the system and will make any potential failures less of a concern.

Other improvements to the suits result in better mobility and communications. Some may recall a video of NASA astronaut Harrison Schmitt, on the

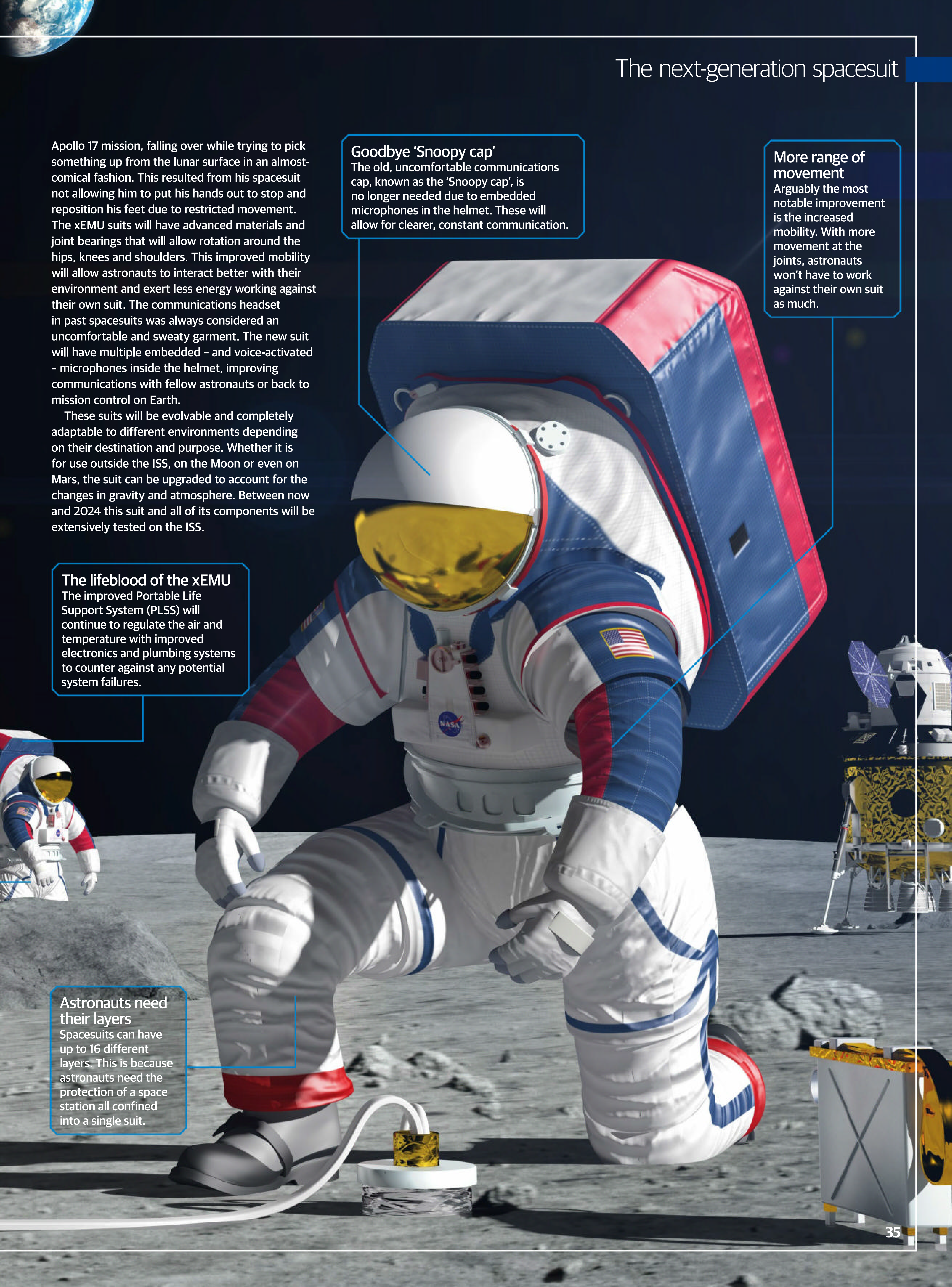


NASA's custom fit
NASA's Anthropometry and Biomechanics Facility will complete a preliminary 3D full-body scan in order to match the astronaut with the best components, ensuring comfort and the broadest range of motion.

© Adrian Mann

Apollo 17 mission, falling over while trying to pick something up from the lunar surface in an almost-comical fashion. This resulted from his spacesuit not allowing him to put his hands out to stop and reposition his feet due to restricted movement. The xEMU suits will have advanced materials and joint bearings that will allow rotation around the hips, knees and shoulders. This improved mobility will allow astronauts to interact better with their environment and exert less energy working against their own suit. The communications headset in past spacesuits was always considered an uncomfortable and sweaty garment. The new suit will have multiple embedded – and voice-activated – microphones inside the helmet, improving communications with fellow astronauts or back to mission control on Earth.

These suits will be evolvable and completely adaptable to different environments depending on their destination and purpose. Whether it is for use outside the ISS, on the Moon or even on Mars, the suit can be upgraded to account for the changes in gravity and atmosphere. Between now and 2024 this suit and all of its components will be extensively tested on the ISS.



Goodbye 'Snoopy cap'
The old, uncomfortable communications cap, known as the 'Snoopy cap', is no longer needed due to embedded microphones in the helmet. These will allow for clearer, constant communication.

More range of movement
Arguably the most notable improvement is the increased mobility. With more movement at the joints, astronauts won't have to work against their own suit as much.

The lifeblood of the xEMU
The improved Portable Life Support System (PLSS) will continue to regulate the air and temperature with improved electronics and plumbing systems to counter against any potential system failures.

Astronauts need their layers
Spacesuits can have up to 16 different layers. This is because astronauts need the protection of a space station all confined into a single suit.

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DO WE NEED TO REWRITE EARTH'S HISTORY?

From metal rains to devastating explosions, new discoveries and surprising theories are changing how we look at the early days of our planet

Reported by Giles Sparrow

The era of Earth's formation, alongside the other planets in orbit around the young Sun, has long been seen as a time of dramatic collisions and cataclysmic encounters between newborn planets, but new discoveries have suggested that conditions could have been even more violent than previously suspected. And according to one theory, the most devastating event in our planet's entire history was triggered not by a chance encounter with a random rogue planet, but by a ticking timebomb beneath Earth's own surface.

Astronomers have pinned down the age of the Earth with surprising precision to 4.54 billion years, give or take a few tens of millions of years. Our planet's active geology makes it impossible to find surface rocks from this time that have not been physically and chemically altered in the aeons since, but meteorites that occasionally crash to Earth bring raw materials that are essentially unaltered since the early days of the Solar System.

Scientists use the relative proportions of radioactive elements in these stray space rocks to date them in much the same way as the well-known carbon-14 isotope is used to date much younger archaeological remains. They show that the minerals which ended up as important components of the rocky planets condensed out of the young solar nebula over a period of around 50 million years.

However, big questions still remain about exactly how the Earth and other rocky planets formed. Scientists agree that the basic process was one of 'collisional accretion' - bigger and bigger asteroids coming together and coalescing, at first through chance collisions but eventually at an accelerating rate as the gravity of the largest bodies caused their growth to snowball. Eventually, the inner Solar System was dominated by a few large bodies called planetesimals that in turn collided to form the four rocky planets we know today.

Until relatively recently, planetary scientists had assumed that the raw materials in these planetesimals were a somewhat random jumble of elements - similar to the grainy 'chondrite' meteorites that still occasionally fall to Earth today. The assumption was that once the accretion process was more or less over, the largest surviving bodies heated up. Their interiors melted through, with iron and certain other elements known as siderophiles sinking down to create a molten core, while the remaining silicate-based rocks formed a surrounding mantle and crust in a process called differentiation.

A surprising discovery, however, has turned this story on its head. In 2006 a new dating technique revealed that iron meteorites are much older than previously thought, dating back to the very earliest days of the Solar System. This means that planetesimals were getting hot enough to melt through and develop iron cores well before they came together to make the present-day planets.

So where did they get the energy from? Answering this question opens an amazing window into the early Solar System. The only explanation for such early super-heating of what would have been relatively small worlds is that it was boosted by an abundance of radioactive elements - specifically forms of iron and aluminium that release their energy and decay into stable forms within just a couple of million years. The only plausible source for such materials is a nearby supernova - and perhaps if a massive star exploded close to our Solar System in the moment of its birth, that same supernova actually triggered the collapse of the nebula that formed the Sun in the first place?

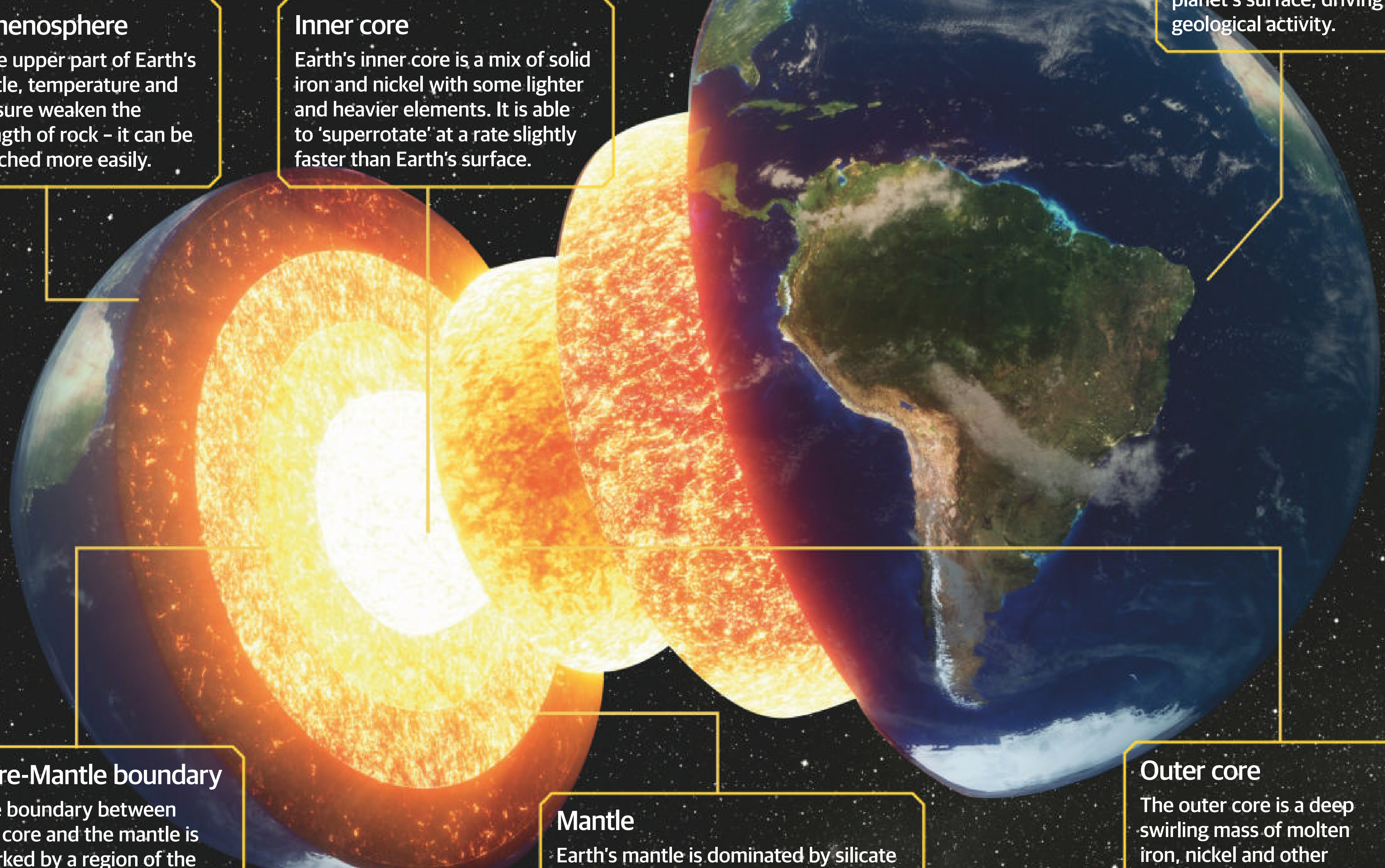
The discovery that the planetesimals already had iron-rich cores helps shed light on another interesting question - why do Earth's crust and mantle still retain relatively large amounts of siderophile elements that should, according to traditional geological models, have sunk into the core shortly after Earth's formation? In 2015, an ingenious experiment by researchers at Lawrence Livermore National Laboratory in California offered a possible explanation.

A team led by Dr Richard Kraus simulated asteroid bombardments at various speeds using the 'Z machine' - a powerful electromagnetic 'gun' used for researching high-density, high-temperature physics. They found that instead of simply sinking down to the centre of the Earth, the iron cores of incoming planetesimals were likely to evaporate, forming a mist that would have rapidly condensed, raining droplets of liquid metal onto Earth's still-molten crust that soon became mixed into the mantle. In this way, even as iron and siderophiles from the mantle were drained into the core, the supply was constantly being 'topped up' from above.

> " If you drill into the Moon it's possible you could find remnants of the explosion"
>
> **Wim van Westrenen**

Inside planet Earth

Our world's internal structure seems to be more complex than previously thought



Asthenosphere
In the upper part of Earth's mantle, temperature and pressure weaken the strength of rock - it can be stretched more easily.

Inner core
Earth's inner core is a mix of solid iron and nickel with some lighter and heavier elements. It is able to 'superrotate' at a rate slightly faster than Earth's surface.

Crust
Earth's outer crust is broken into tectonic plates that move slowly but inexorably across the planet's surface, driving geological activity.

Core-Mantle boundary
The boundary between the core and the mantle is marked by a region of the lower mantle where rocks become molten.

Mantle
Earth's mantle is dominated by silicate minerals that change their form at a transition zone around 500 kilometres (311 miles) down.

Outer core
The outer core is a deep swirling mass of molten iron, nickel and other elements. Electric currents generated by the churning iron create a magnetic field.

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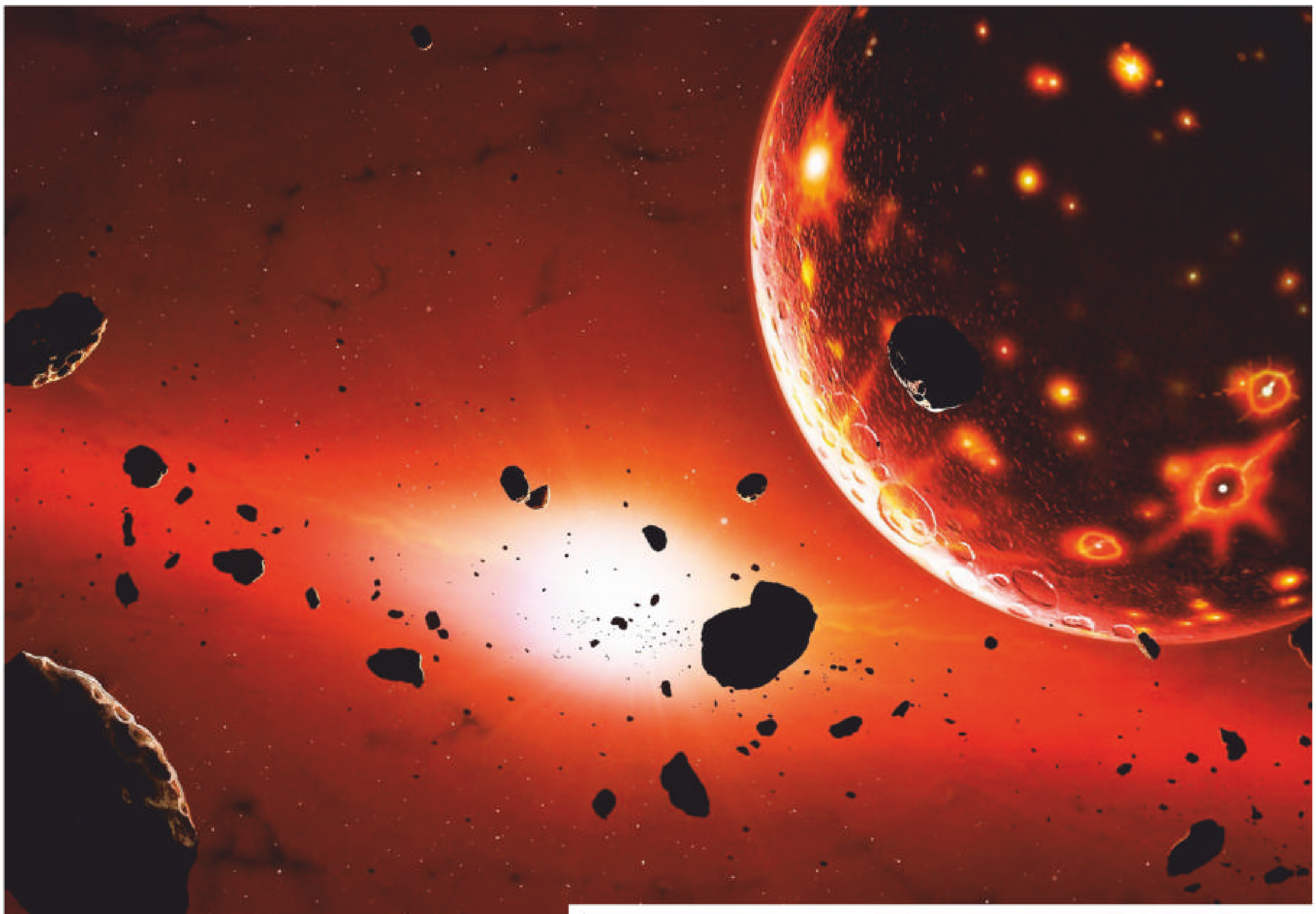

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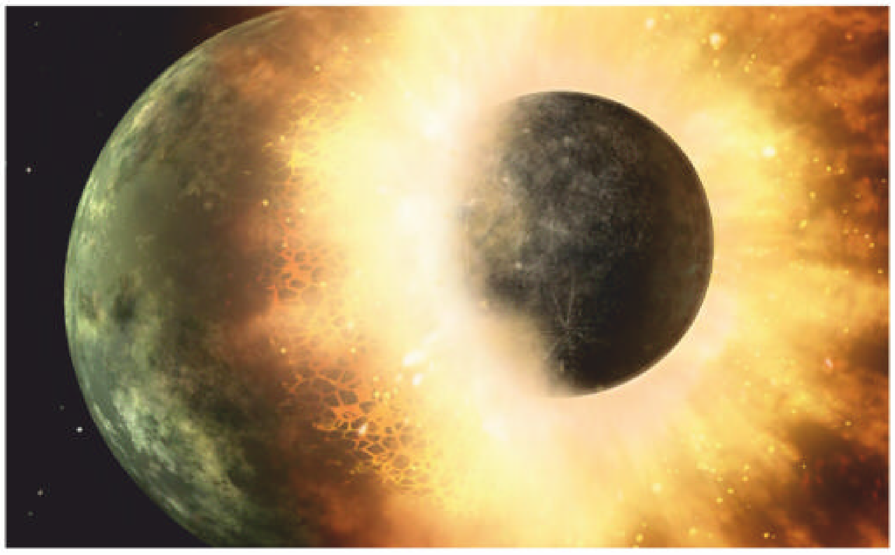

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According to current thinking, the largest and most devastating planetesimal collision of all happened around 4.5 billion years ago. A Mercury- or Mars-sized world, sometimes called Theia, collided with the primordial Earth in an interplanetary smash that destroyed the smaller world completely and ejected much of its material, along with a substantial chunk of Earth's own mantle, into orbit around our still-reeling planet. In a surprisingly short time, these rocks coalesced to form the Moon we know today.

That, at least, is the sequence of events put forward by the giant-impact hypothesis - the most widely accepted explanation for how Earth's outsized Moon came to be. The Moon's origins have always been a challenge for astronomers - its huge size means that it simply could not have formed from 'left-over' raw materials orbiting the young Earth, so for a long while it was assumed to be a captured world that had formed elsewhere in the inner Solar System. In the 1970s, however, analysis of material brought back by the Apollo Moon landings ruled out the 'stray planet' idea - lunar rocks show similarities in geology that mean the Moon must have formed at the same distance from the Sun as Earth.

Under the circumstances, the giant-impact hypothesis seems to be the best option on offer - a means of putting large quantities of Earth-like material into orbit around our planet to form the Moon. But that doesn't mean it's without its problems, as Professor Wim van Westrenen of Vrije University Amsterdam points out: "The classic giant-impact models predict that the Moon should be made predominantly of Theia material, whereas sample analyses showed that the Moon seems to be made exclusively of Earth materials. From 2012 onwards several computer models of alternative impacts made the Moon predominantly of Earth materials, but these alternative impacts only work when you assume very large angular momenta for the Earth-Moon system - much larger than we find in the system today. Models for getting rid of this angular momentum have been published, but are certainly not universally accepted. In short, if you get the physics right you predict the wrong chemistry, and getting the chemistry right leads to problems in physical properties of the Earth-Moon system."

Van Westrenen's primary interest is in the later geological evolution of the Earth, Moon and other planets, which he studies using high-pressure, high-temperature physics experiments. It was while working with physicist Professor Rob de Meijer that he first began to have concerns about the giant-impact hypothesis. "Rob asked me if it was known

Top: As the largest bodies in the early solar nebula developed substantial gravity, they pulled in more material from their surroundings, growing in a snowball effect to form larger planetesimals

Above: It's suspected that a Mars-sized world called Theia collided with a young Earth

By the numbers Earth's core

c.1.88

gigacandela per square metre

c.8 million-times brighter than a laptop screen

5,800°C

Surface temperature

As hot as the surface of the Sun

6,800km

Twice the size of the Moon

0.07° a year

Inner core rotation rate

At the equator, a spot on Earth's solid inner core directly beneath your feet creeps 20 metres 'ahead' of you each day.

2,440km

Diameter of solid inner core

Distance from London to Greece

8g/cm3

Average density

About as dense as bronze

1%

The proportion of gold in Earth's core

Enough to cover Earth's surface to a depth of 30 centimetres (12 inches)

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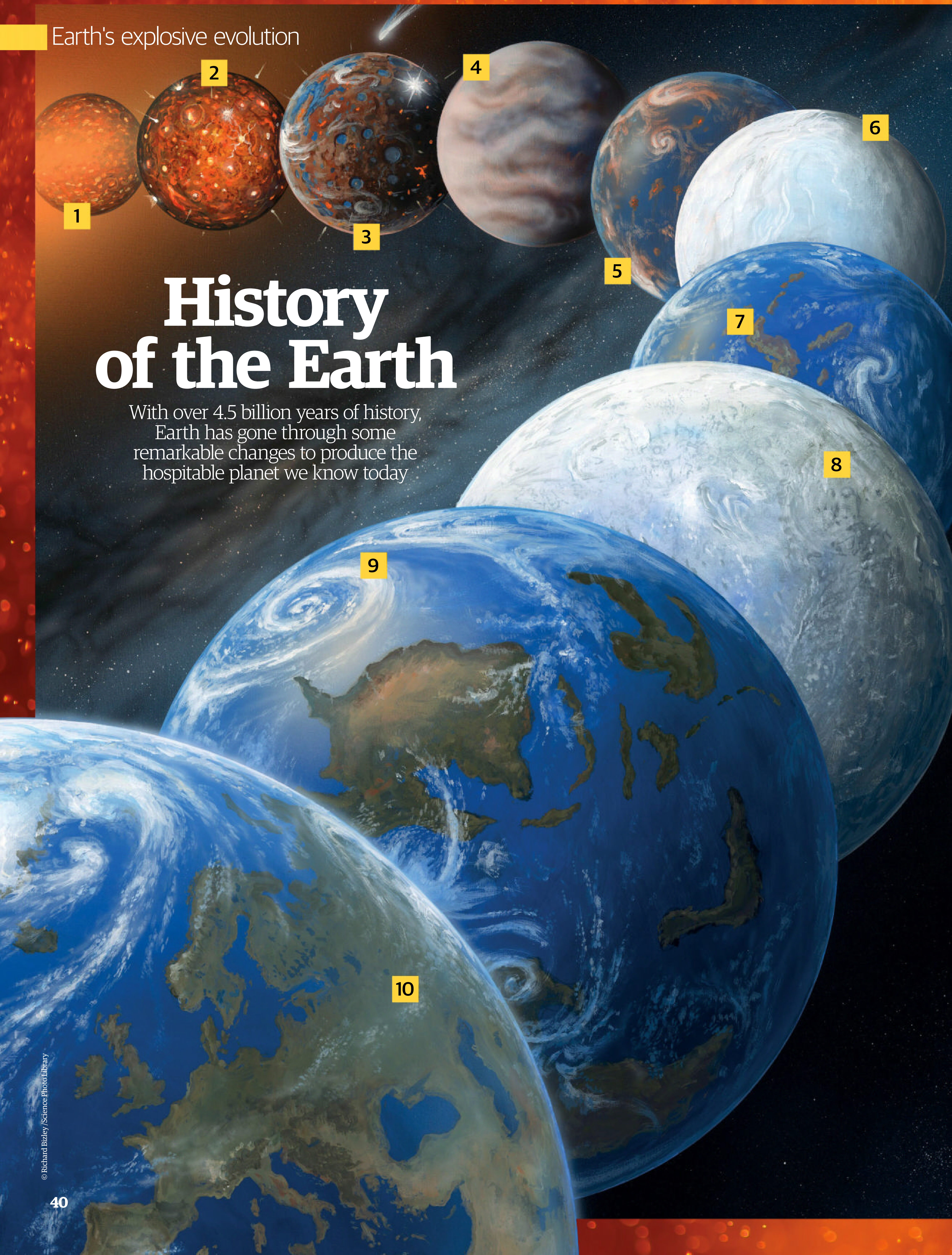
History of the Earth

With over 4.5 billion years of history, Earth has gone through some remarkable changes to produce the hospitable planet we know today



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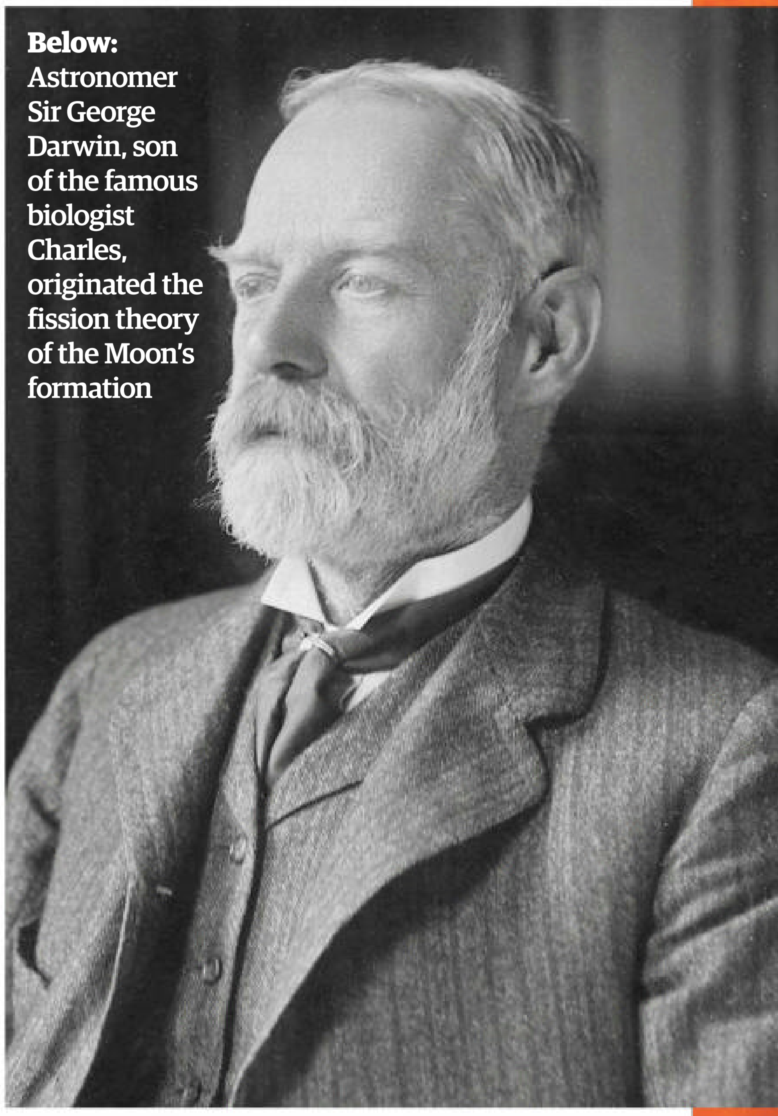
how the Moon was formed. I said sure, by the giant impact. That has been known since the mid-1970s. He started probing into how sure we are of this. And the more I started digging up evidence to show Rob that the giant-impact model was correct, the more I found that there was a huge chemical issue with the giant-impact models: it predicted differences between Earth and Moon chemistry that we simply did not observe."

De Meijer and van Westrenen had previously worked on another project that would prove the key to their own theory of the Moon's formation. In 2008 they had looked into the feasibility of remarkable natural phenomena called georeactors. These are natural nuclear power plants, created when concentrations of radioactive isotopes such as uranium undergo a nuclear chain reaction. "We asked if such a reactor could exist deep in the Earth," recalls van Westrenen. "Our answer was yes. We then combined our work on georeactors with knowledge of Moon rocks to devise our alternative model."

This fresh take on the Moon's formation drew, in part, on one of the oldest lunar origin theories, first proposed by George Darwin in 1879. Known as the fission model, Darwin's idea involved an ancient Earth spinning so fast that it bulged outwards until eventually a substantial chunk of the equatorial region broke away to form the Moon. The big problem for this idea is that it doesn't match the physics of today's Earth-Moon system: the ancient Earth would need to have spun on its axis at least once every 2.7 hours in order to break up, but if this was the case then we'd expect the Earth-Moon system to be spinning much more rapidly today.

This is a more extreme version of the angular momentum problem that also plagues the giant-impact hypothesis: it's well known that Earth's



Below: Astronomer Sir George Darwin, son of the famous biologist Charles, originated the fission theory of the Moon's formation

Source: Wikipedia commons

1 4.54 billion years ago: the Earth forms

Earth and the other rocky planets formed through violent collisions between planetesimals. The core formed rapidly as heavy elements filtered down through the mantle towards the centre of the planet, while bombardment continued to spread metallic elements across the surface.

2 4.5 billion years ago: origin of the Moon

The Moon formed 50 to 100 million years after the Earth. The most popular current theory for the Moon's formation involves a substantial part of the mantle being blasted away from Earth by a giant impact, but some argue that this impactor should have left geological traces that have not been found.

3 4.1 to 3.8 billion years ago: Late Heavy Bombardment

Earth and the inner planets were hammered by a torrent of high-energy impacts that left their surfaces heavily cratered. This Late Heavy Bombardment is thought to have been triggered as shifts in the orbits of the giant outer planets disrupted huge clouds of rocky and icy debris.

4 3.5 billion years ago: first life

The earliest traces of simple life date to about 3.6 billion years ago, and the first actual fossils are 100 million years younger. These stromatolites were layered stacks of single-celled organisms that survived in shallow waters by photosynthesis, transforming carbon dioxide into food using sunlight.

5 2.4 billion years ago: Great Oxygenation Event

For hundreds of millions of years, geological changes absorbed the oxygen being pumped into the atmosphere by life to create oxidised minerals. Eventually the oxygen began to build up in the atmosphere, transforming the air and making it toxic to many simple life forms.

6 2 billion years ago: eukaryotic life

A major change in the nature of life, though they were still only single-celled life forms, the eukaryotes used a nucleus to contain their genetic information and developed a variety of specialised 'cell machinery' to take advantage of different energy sources.

7 750 million years ago: snowball Earth

A chance arrangement of Earth's shifting continents close to the equator led to increased 'weathering' of rocks – a process that pulled carbon dioxide out of the atmosphere and led to a sudden and dramatic global cooling. Glaciers spread from the poles down towards the equator in a series of ice ages.

8 541 million years ago – Cambrian explosion

The dawn of the Cambrian geological period saw a huge explosion in the variety of multicellular life, and the appearance of most of the major animal groups known today. One theory suggests this was triggered by chemical changes to the sea that made hard shells and teeth viable for the first time.

9 252 million years ago: the Great Dying

The largest mass extinction in the history of Earth wiped out much of the previous life on land and at sea, paving the way for the rise of the dinosaurs. This may have been triggered by the union of all Earth's continents into a single equatorial landmass called Pangaea and the accompanying volcanic eruptions.

10 65.5 million years ago: death of the dinosaurs

The most famous mass extinction occurred when a large asteroid struck the present-day Gulf of Mexico region at the end of the Cretaceous period. The climate crisis that followed wiped out the ruling dinosaur reptiles – except the birds – leaving the path clear for the rise of mammals and eventually humans.

rotation has slowed over the aeons - but not by nearly enough to lend a hand to this theory.

The Dutch scientists started wondering whether a georeactor deep inside the ancient Earth could provide the answer. In the right conditions this could have been more than a low-energy, long-running event like those seen at Oklo: a much larger and more violent instantaneous burst of energy - not so much a small nuclear power plant as an atomic bomb of vast proportions.

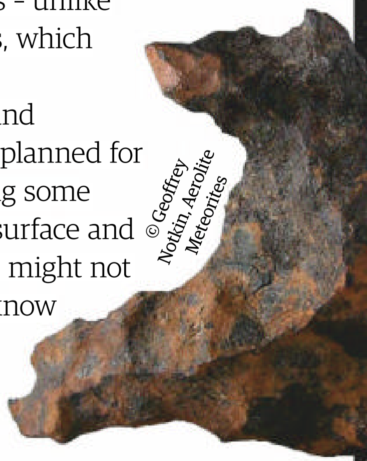
The georeactor would have formed on the boundary between Earth's core and mantle due to a concentration of radioactive materials in the form of uranium, thorium and plutonium. If evenly distributed they would still need to be thinly spread across Earth at least 15 times to form a georeactor, but there are various ways they could be concentrated together. There's increasing evidence that the cosmic microwave background (CMB) is as diverse, in its own way, as Earth's surface, with distinct variations in the way seismic waves spread in different regions.

Waves spreading through reservoirs of molten magma could help to further compress a local concentration of radioisotopes, as could shockwaves from a mid-sized planetesimal impact on the surface. Once tipped over the edge, the nuclear reaction would have been sudden and violent, releasing as much energy in a few milliseconds as all of Earth's electricity plants could generate in billions of years. With the Earth already spinning faster than it does today, a cataclysmic shockwave spreading out from the CMB would have provided the extra 'kick' needed to blow the Earth apart, ejecting enough material to form the Moon before the traumatised pieces came back together.

So is this how the Moon really formed? Van Westrenen freely admits that the wider planetary science community remains highly sceptical. "That's okay - Rob and I did not expect everyone would move to agreeing with us. We are happy the model is out there for everyone to read and criticise if they wish. If others have superior models then I would be happy to agree with them, but since publication I have not come across any model that is significantly better constrained than ours."

Convincing proof of the georeactor theory, however, would be to find evidence of the 'nuclear waste' formed at the time. "Evidence would not be visible on Earth anymore because the mantle has been thoroughly mixed in the past 4.5 billion years," continues van Westrenen. "But there should be evidence in Moon rocks. Because of interaction with solar wind the isotopic signals would have been erased in near-surface rocks such as the Apollo samples, but if you drill into the Moon it's possible you could find remnants of the explosion. This is a testable hypothesis - unlike the giant-impact hypothesis, which is not very testable."

With a host of scientific and commercial lunar missions planned for the next few years, including some which aim to drill into the surface and return samples to Earth, we might not have long to wait until we know if history needs a rewrite.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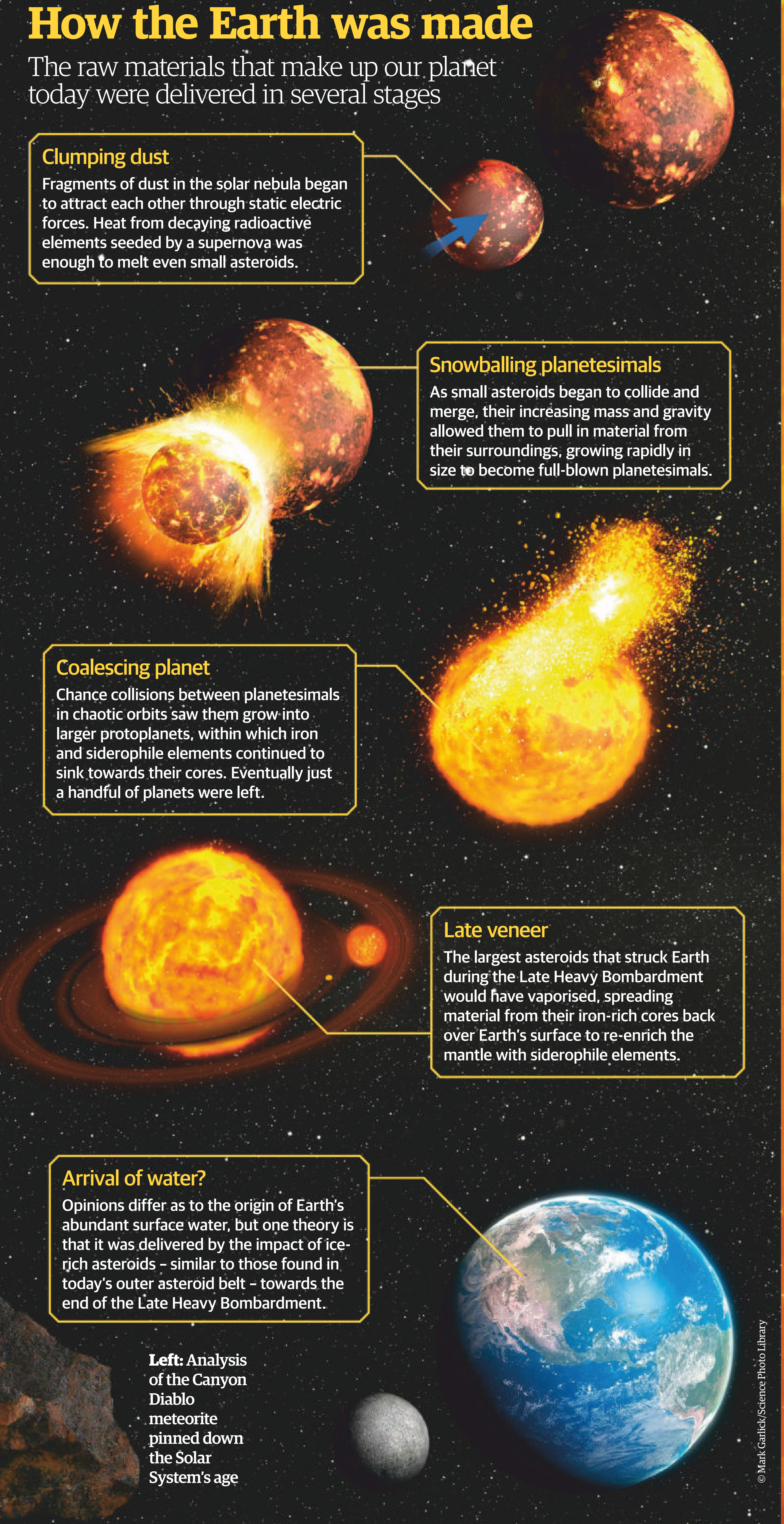
Left: Analysis of the Canyon Diablo meteorite pinned down the Solar System's age



How the Earth was made

The raw materials that make up our planet today were delivered in several stages

Clumping dust

Fragments of dust in the solar nebula began to attract each other through static electric forces. Heat from decaying radioactive elements seeded by a supernova was enough to melt even small asteroids.

Snowballing planetesimals

As small asteroids began to collide and merge, their increasing mass and gravity allowed them to pull in material from their surroundings, growing rapidly in size to become full-blown planetesimals.

Coalescing planet

Chance collisions between planetesimals in chaotic orbits saw them grow into larger protoplanets, within which iron and siderophile elements continued to sink towards their cores. Eventually just a handful of planets were left.

Late veneer

The largest asteroids that struck Earth during the Late Heavy Bombardment would have vaporised, spreading material from their iron-rich cores back over Earth's surface to re-enrich the mantle with siderophile elements.

Arrival of water?

Opinions differ as to the origin of Earth's abundant surface water, but one theory is that it was delivered by the impact of ice-rich asteroids – similar to those found in today's outer asteroid belt – towards the end of the Late Heavy Bombardment.

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INTERVIEW BIO

Sean Carroll
Carroll is a renowned theoretical physicist exploring topics such as quantum mechanics, gravitation, cosmology and so many more. He is a research professor of physics at the California Institute of Technology in Pasadena, California, and also a research professor at the Santa Fe Institute in New Mexico.

Carroll has written a number of books including *The Big Picture*, *The Particle at the End of the Universe*, *From Eternity to Here* and many others. All delve into the deepest mysteries at the core of our universe, and his latest addition, *Something Deeply Hidden*, is another exceptional read.

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QUANTUM MECHANICS 101

With a new book recently hitting shelves, Sean Carroll speaks to **All About Space** about the world of super strange physics and why there needs to be more attention on the subject

Interviewed by Lee Cavendish

Richard Feynman said about 50 years ago: "I think I can safely say that nobody understands quantum mechanics." Is that still the case?
I think that is the case as long as we interpret what he says in a certain way. What is absolutely the case is that physicists don't agree about quantum mechanics. Even if one physicist does understand it, nobody else thinks that they understand it. As a field I would say it's safe to say that physicists don't claim to understand quantum mechanics.

Did you write the book to make quantum mechanics more accessible, or was it to outline that there are issues and call for new physics?
I definitely didn't want to just outline the issues. I wanted to present the plausible way forward based on [Hugh] Everett's 'many-worlds' version of quantum mechanics, while also arguing that even if that approach is wrong, it's still very important that we have an approach, that we don't just wallow in the mystery of quantum mechanics and that we stop just saying: "Wow. It's weird. It's spooky. It'll never be understood" and try to bring it into the realm of ordinary physics.

What is the many-worlds theory?
In any version of quantum mechanics you have this weird thing where an electron, or some other quantum system, can be in a 'superposition' of different possibilities. The standard way of thinking about it is an electron can be spinning either clockwise or counterclockwise. In quantum mechanics, it's in a superposition of both, but when we observe it, we only ever see clockwise or counterclockwise. This is a mystery in standard quantum mechanics, and in many-worlds what we say is, when you observe the electron, you become a superposition where it's part of the state of the universe if the electron was spinning clockwise and you saw it spinning clockwise, and another part of the state of the universe if the electron was spinning counterclockwise and you saw it spinning counterclockwise. These two possibilities become two separate worlds.

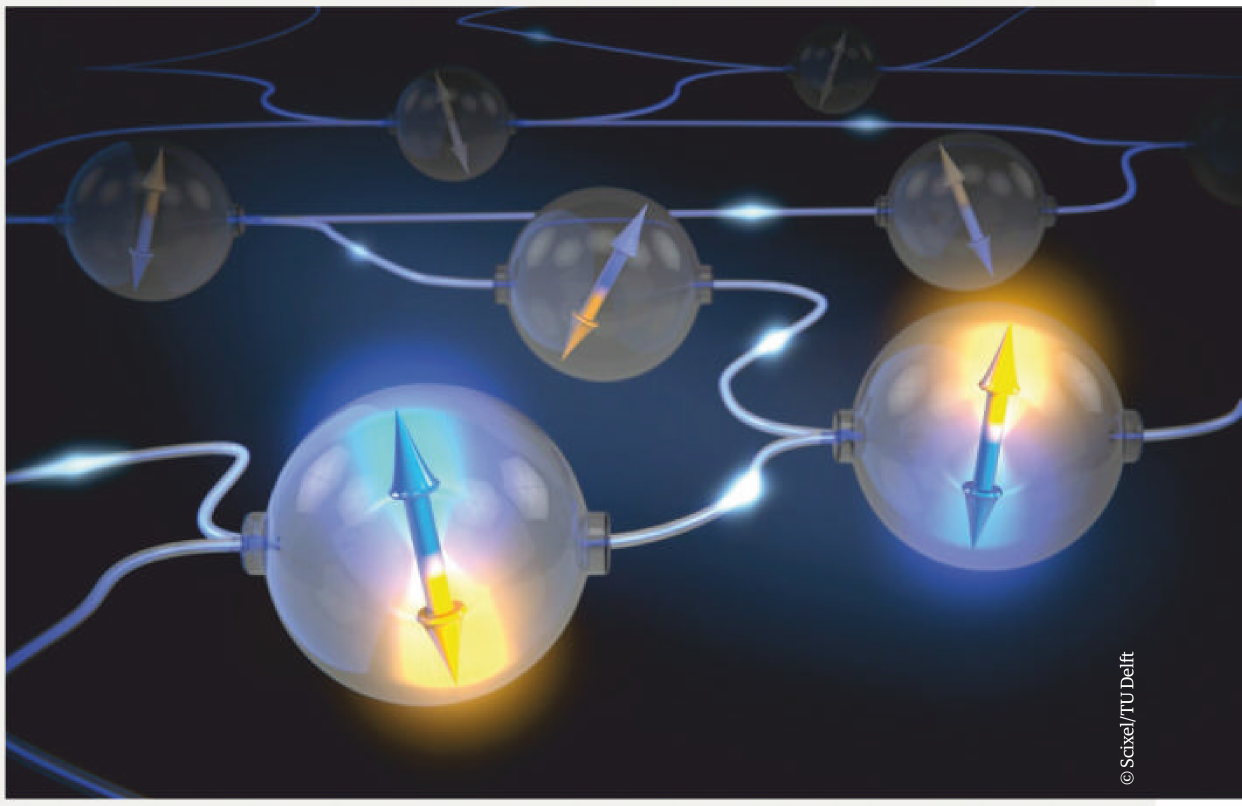
Would it be correct to say that there could be an infinite number of us in there, and so many different universes, based off a change in a certain instance?
We actually don't know whether the number of worlds is finite or infinite. That's an open question we're not sure about. But certainly there are a lot. There could be an infinite number. Whenever a tiny quantum system that is in a superposition becomes entangled with the wider world around it, the universe branches. That's happening all the time. It's happening thousands of times a second, just in the room you're sitting in right now.

When you say 'things become entangled', is that in the instance of making the measurement?
One of the benefits of [many-worlds] is the idea of a 'measurement', or an 'observation', disappears from the theory. There's nothing special about measurements or observation. It's really just when small quantum systems in superpositions become entangled with the big quantum system. That's when the branching happens.

That can happen when someone is looking at it, because a person looking at it is a big quantum system, but it can also happen in the natural course of things, when no one is watching.

One popular example of superposition is the Schrödinger's cat thought experiment. Is that a good example of explaining how a living creature becomes part of a quantum system?
Yeah, and one of the ideas behind the thought experiment was to drive home the vagueness of the standard way of thinking about quantum mechanics. Many-worlds and its respectable alternatives are very explicit about what it means to branch and collapse the wave function, or whatever it is, but the standard treatment is very vague. There are people who want to say "tiny microscopic systems can be in quantum superposition, but big macroscopic systems cannot". Schrödinger's cat was supposed to be a way of illustrating that, in principle, we could take a quantum superposition and magnify it up to the macroscopic world, even into two different states of a cat.

Is it correct to say that quantum mechanics is not just based on the subatomic behaviours, but can also have a more profound effect on some of the universe's larger objects?
That's what we think is true. It's something that is true if many-worlds is true, or if something was



Right: Quantum entanglement is a strange phenomenon that transfers information between particles

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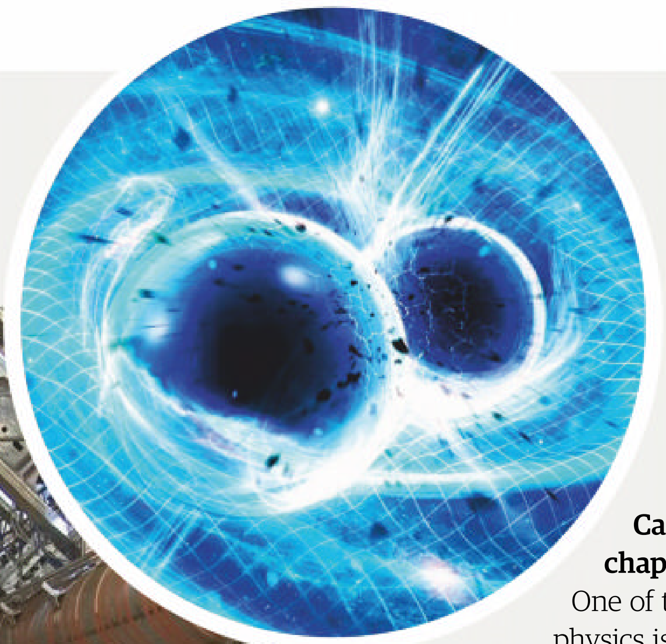


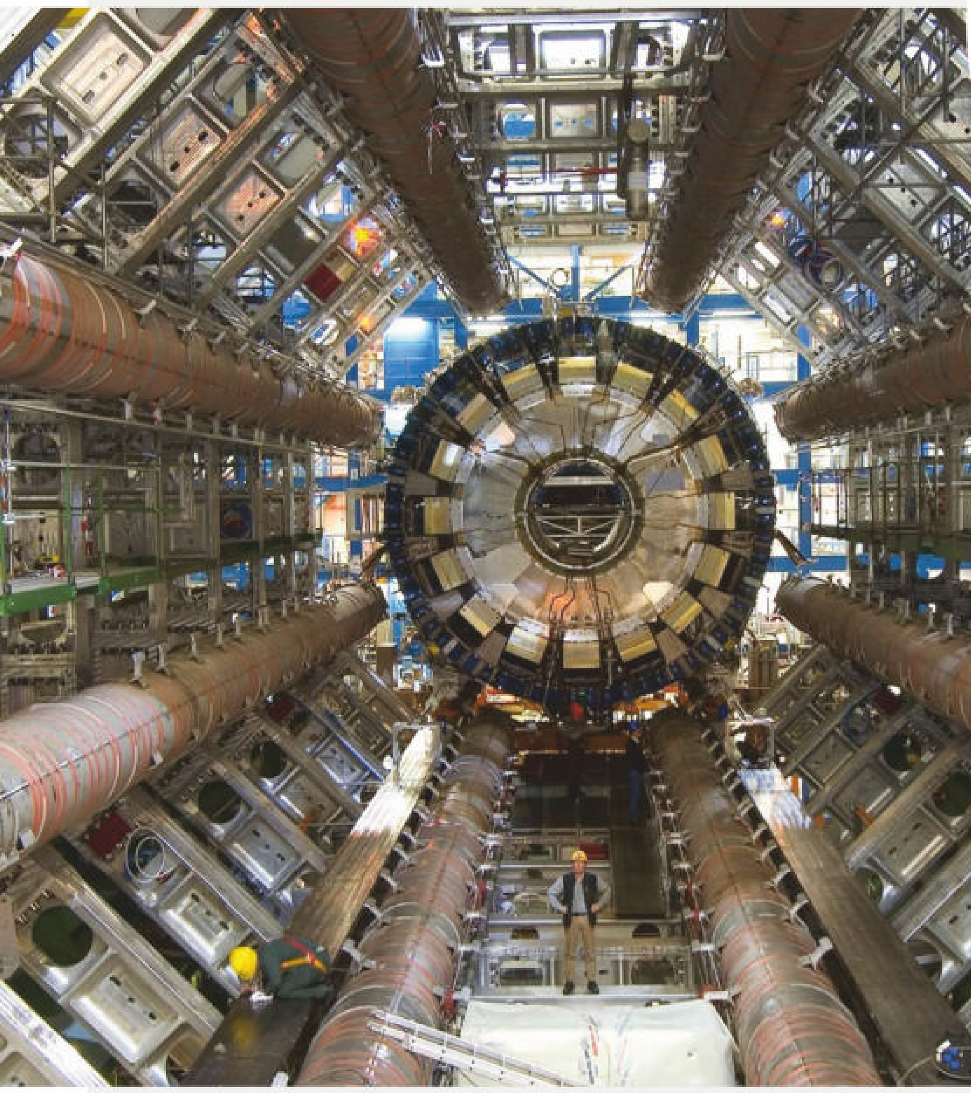
true with another version of quantum mechanics. We actually don't know what the right version of quantum mechanics is, so I can't give you a definite answer.

Can you tell us a bit more about your chapter on space-time?

One of the long-standing mysteries of theoretical physics is trying to quantise gravity. This is one of the biggest puzzles that we have in modern physics - reconciling the rules of quantum mechanics with the rules of gravitation, general relativity, Einstein's theory of gravity. My suggestion is that part of the problem is that we've been starting with classical theories and trying to quantise that, rather than starting with quantum theory from the start and finding the classical limit within it. What I tried to explore in the book is how quantum entanglement can help us understand how to knit together quantum mechanical states into the big classical space-time that we live in.

The 1927 Solvay Conference was a meeting of some of the brightest minds. How influential was this conference for quantum mechanics?

Some of the biggest, most important steps in quantum mechanics had been taken in 1926, and they were able to get all the right people, in the right place at the right time, in 1927 to really hash out what it all meant. You know, [Albert] Einstein, [Erwin] Schrödinger, [Niels] Bohr, [Paul] Dirac, [Wolfgang] Pauli and so forth. It was very influential because there were still some issues about interpretation, what it all meant, and remember this is a period where every other year, you would just overthrow the laws of physics and try something new. The idea that they'd finally gotten it was very tempting, and people like Bohr tried to say, "Yes!



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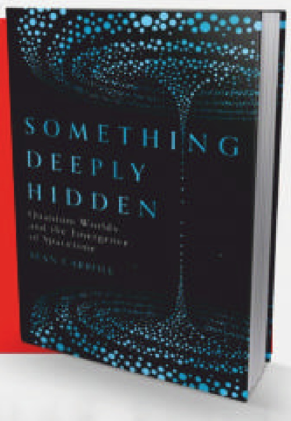
Above: Carroll is trying to understand the nature of gravity at a quantum level

Left: The Large Hadron Collider is capable of breaking atoms down to observe at a quantum level

Below: The 1927 Solvay Conference was a meeting of the sharpest minds, focused on quantum mechanics

Something Deeply Hidden: Quantum Worlds and the Emergence of Spacetime

Sean Carroll's latest book is a comprehensive review of quantum mechanics. He suggests that the underlying theory that rules all the cosmos is the many-worlds theory. It is published by Oneworld, and a hardback copy is available for £20.00.



Source: Wikipedia Commons

Right: Schrödinger's cat is a popular explanation for an aspect of quantum behaviour

©Getty; NASA/ESA/ESO

> "Experiments definitely led the way in forcing physicists to confront quantum mechanics"

We've finally gotten it! Let's just agree and move on to other things." And people like Einstein tried to say, "No, no, no. We're not there yet. We have much more work to do."

Why do you think all these major discoveries about quantum mechanics happened around the late-19th and early 20th century?
I think it's a combination of different things. Part of it was just technology, which is always true, like experiments get better and things that were just hints - or vague suggestions - before become impossible to ignore in the data. One of the biggest things was simply that we began to understand atoms. The idea that an atom has an electron and has a nucleus, and the electron is orbiting. This idea was put together in the early years of the 20th century by people like [Ernest] Rutherford and so forth. But that idea doesn't work in classical mechanics. We eventually figured out how you need quantum mechanics to explain that, so the experiments definitely led the way in forcing physicists to confront quantum mechanics.

I understand there's a story behind the title of your book, *Something Deeply Hidden*. Can you please explain it?
This was a quote from Einstein. Later in life, when he was writing some version of his memoirs, he mentioned this formative moment when he was very young and he was handed a magnetic compass. He was just a kid, and you and I would just play with it, but he was Einstein, so he was really puzzled by the fact that you could move the compass around and it would always know which direction was north. He didn't know about magnetic fields or anything like that, but he said: "You know, there must be something deeply hidden that explains why things are this way."

I think that's a great phrase, both because it encompasses what a good physicist's attitude should be - that we should always try to figure out what is going on behind the scenes - and also it very much reflects Einstein's attitude about quantum mechanics decades later. He said, "Look, we can't just say this is good enough. We have to look for what's going on underneath the surface that might make sense of all this."

What were other physicists' receptions to Einstein's attitude of quantum mechanics?
Well, he had one or two allies - Schrödinger was on his side - but mostly he lost the public-relations battle. Mostly people sided with Bohr and said, "Quantum mechanics is in good enough shape, and rather than worrying about the foundations of quantum theory, we should move on and start applying it to nuclear physics, particle physics and materials and things like that."

We use a lot of our technology now based off this science. How is that the case, even though we struggle to fully understand it?
This is why you have to be very careful when you say things like physicists don't understand quantum mechanics. Physicists can use quantum mechanics really well. We can use it to build giant particle accelerators and discover the Higgs boson, but we can also use it to make transistors and lasers and much of modern technology.

The analogy I like to use is this: physicists understand quantum mechanics in the same way that you and I understand our smartphone. We can use them, we can call up the apps, we can take pictures, we can text and phone and whatever, but we don't know what's going on inside. Well, most of us are not computer designers in that sense. That's fine if all you want to do is use the phone to call your friends, but if your goal is to understand the fundamental laws of nature, then maybe you want to dig a little bit deeper.

What are your thoughts on quantum computing, and do you think we'll be capable of using it in the near future?
I wish I knew. It's certainly possible in principle. There's definitely been a tremendous amount of work to show how powerful quantum computers can really be. And in practice, it's hard. The whole point of quantum computers is the entanglement between the different bits that are doing the quantum calculation. That entanglement is very fragile. It's very easy to break it just by being in a warm room by having some photons scatter off some pieces of your quantum computer. Whether or not they're able to solve that problem will be the big question.

It's possible they'll be good at building small quantum computers, but big ones will elude us, or it's possible we'll have a breakthrough and it'll be the way that computers are built - powerful computers anyway - in the immediate future.

What kind of potential could these quantum computers have?
Well, there are some problems where you don't really need a quantum computer. A classical computer does perfectly well for sending emails or playing a video game, but there are other problems where there's special capability that quantum computers have, and one that is pretty well known is factoring large numbers.

If you take the number six, you can divide it into two times three, and that's easy enough to do to the number six, but if the number is 100-digits long it's much harder to do. In fact it's really hard.

People use the ability to do that as the basis for encryption; for putting messages in a form that means outsiders can't read them. It turns out quantum computers are kind of good at factoring large numbers, whereas classical computers are not. There are specific problems where quantum computers could be real game changers.

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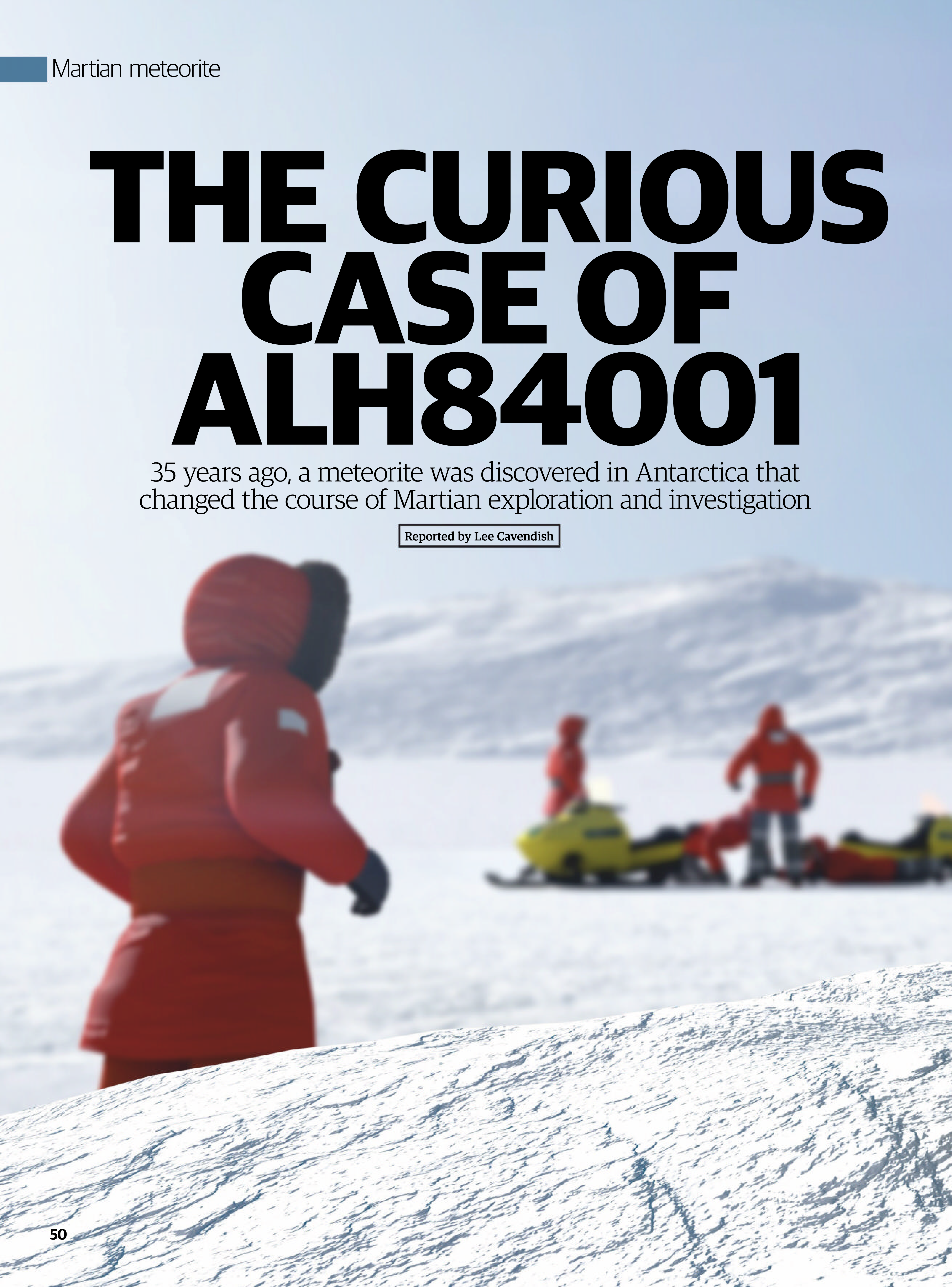
THE CURIOUS CASE OF ALH84001

35 years ago, a meteorite was discovered in Antarctica that changed the course of Martian exploration and investigation

Reported by Lee Cavendish



On 27 December 1984, a piece of rock was found in the Allan Hills region of Antarctica by the Antarctic Search for Meteorites (ANSMET) programme. What they originally identified as a mediocre meteorite turned out to be arguably the greatest catalyst in the field of astrobiology, and in particular the search for life on another planet.

The rock, designated ALH84001 – ALH referring to Allan Hills – was left in the archives for about a decade after it was found, as the ANSMET team labelled it as a piece of leftover space rock from the formation of the Solar System. It was only after further examination it was revealed that this was a unique Shergottite-Nakhlite-Chassignite (SNC) type of meteorite. Even in the mid-1990s astronomers were aware that this type of meteorite could come from Mars after impact events on the Red Planet.

A trio of astronomers put the meteorite under the microscope to have an even more thorough investigation. The results of this analysis would shape the course of astrobiology, and in 1996 Dr David McKay, Dr Everett Gibson and Dr Kathie Thomas-Keprta released a paper in the journal *Science* titled 'Search for Past Life on Mars: Possible Relic Biogenic Activity in Martian Meteorite ALH84001' – it just rolls off the tongue.

It wasn't the catchy title that caught everyone's attention though; the results from this paper showed that the meteorite was one of the oldest Mars samples ever found on Earth. It had formed on our planetary neighbour about 4.5 billion years ago, ejected from the surface 16 million years ago and was drifting through space before touching down on Earth 13,000 years ago. It wasn't its journey that made headlines though. The trio of astrobiologists then claimed that they had found possible evidence for primitive life on ancient Mars.

This received quite the reaction, the most notable of which came from the President of the United States at the time, Bill Clinton, making a public announcement on the discovery. Prior to this

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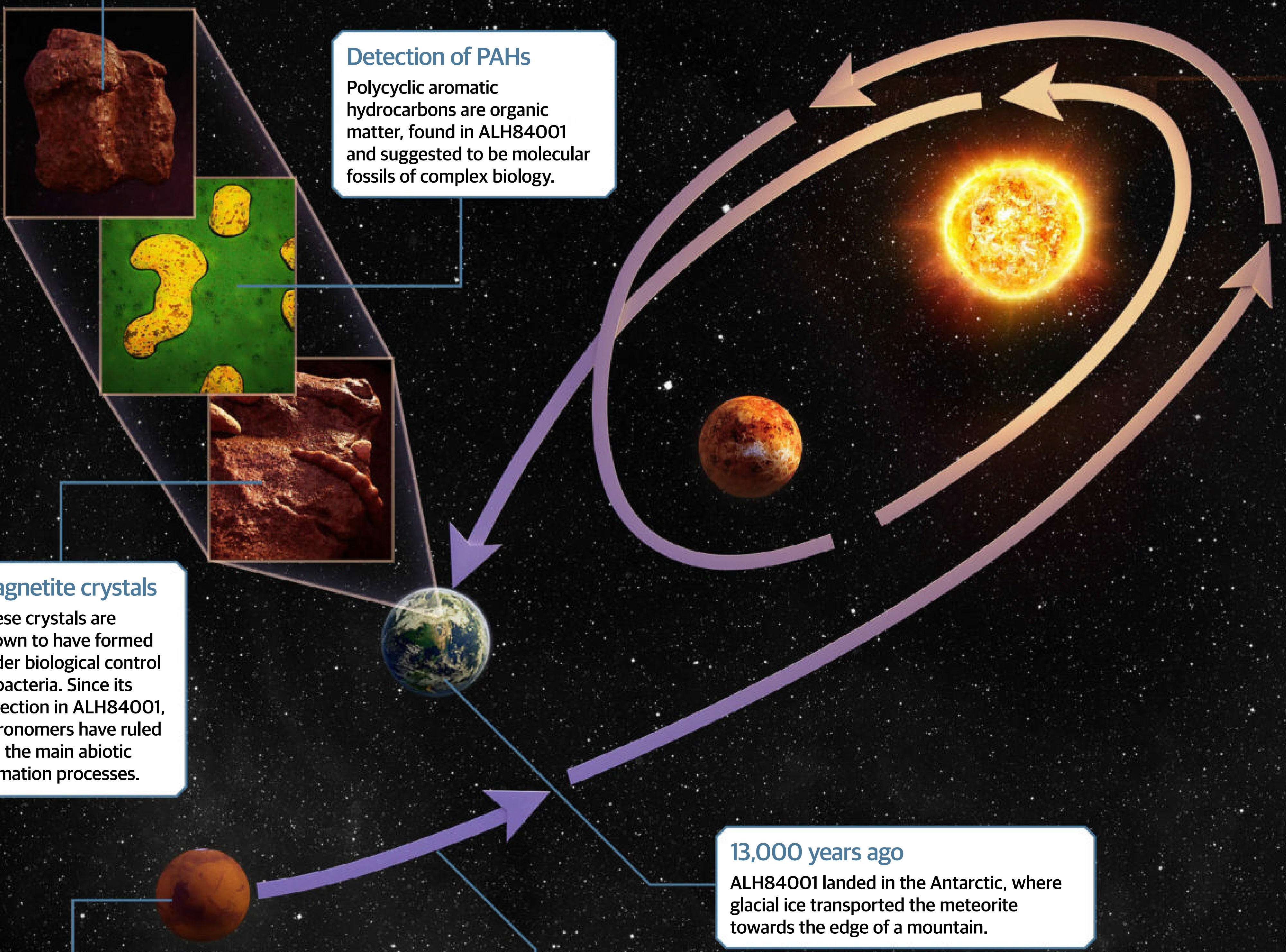
The story of ALH84001

There have been highs and lows, but the love stays the same for this elusive Martian messenger



The four lines of evidence

These four pieces of evidence, when taken collectively, provide a compelling argument for finding signs of ancient life on Mars.

'Worm-like' features

Mineralised spherical and elongated ellipsoidal features bare a resemblance to ancient bacterial life – these are referred to as 'biomorphs'.

Presence of complex carbonate assemblages

The carbonate globules were formed in aqueous processes at low temperatures. These conditions are strikingly favourable for life to prosper.

Detection of PAHs

Polycyclic aromatic hydrocarbons are organic matter, found in ALH84001 and suggested to be molecular fossils of complex biology.

Magnetite crystals

These crystals are known to have formed under biological control of bacteria. Since its detection in ALH84001, astronomers have ruled out the main abiotic formation processes.

4.5 billion years ago

ALH84001 was originally formed from molten rock, crystallised during the planet's formation. Afterwards, water seeped into fractures, creating carbonate minerals.

16 million years ago

An impact, likely from a comet, caused the sample to be ejected into space, where it was frozen and preserved for millions of years.

13,000 years ago

ALH84001 landed in the Antarctic, where glacial ice transported the meteorite towards the edge of a mountain.

35 years ago

The meteorite was discovered in the Allan Hills region, at the end of the Transantarctic Mountain range, in Antarctica by a United States expedition.

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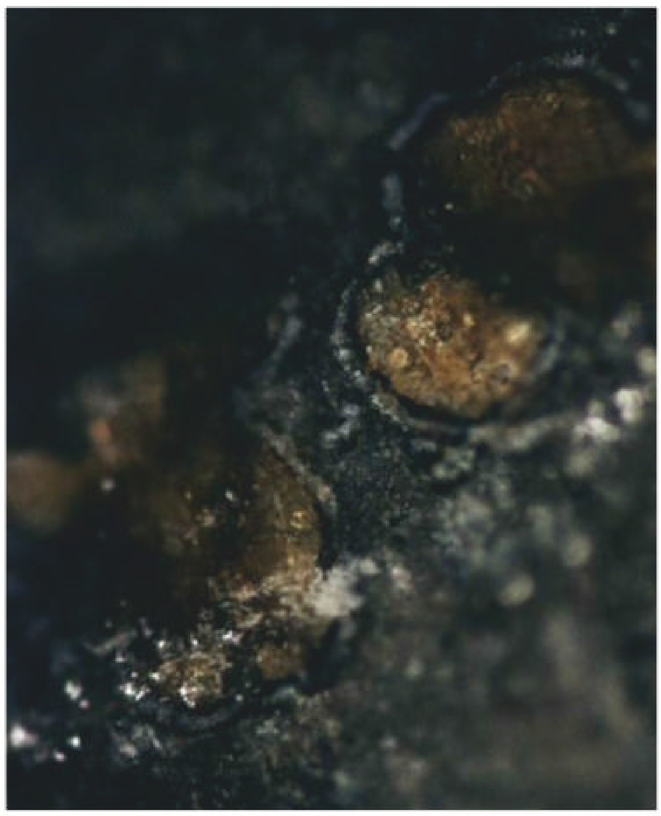

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Left (top): The orange spherical shapes are the carbonate globules found in ALH84001

Left (bottom): Dr Gibson was one of the three scientists who released the pioneering paper

Right: Finding evidence for life on Mars could have serious implications in understanding our own existence

> "Four lines of evidence existed which offered possibilities for the discovery of past biogenic activity on Mars" **Everett Gibson**

announcement, things were not looking good for astrobiology. "The 1990s was a period when NASA's Mars Exploration Program had suffered two major spacecraft failures and was directed to be reduced in scope by the Clinton White House," Dr Everett Gibson, now an emeritus senior scientist within the Astromaterials Research and Exploration Science (ARES) Division at the Johnson Space Center, Houston, Texas, tells **All About Space**. "NASA administrator Daniel Goldin noted the agency's planetary exploration programme was to be reduced by $6 billion [£4.6 billion] over the next five years."

But what made this analysis so credible that even Clinton had to sit and take notice, therefore reinvesting in the space exploration programme? As Gibson explains: "The original *Science* paper noted that within the ALH84001 meteorite's carbonate globules four lines of evidence existed which offered exciting possibilities for the discovery of past biogenic activity on Mars, if it was ever present." Dr Kathie Thomas-Keprta, now a senior planetary scientist at NASA's Johnson Space Center, recalls to **All About Space** that it was "personally and professionally one of the most exciting times of my life."

These four lines of evidence are still unproven to this day, but this discovery derived from microscopic features in the meteorite known as 'globules'. These globules - small, round features in a substance - make up just one per cent of the rock, and McKay and his team found four key points that - when taken collectively - provided unmatched evidence of past life on an ancient Mars.

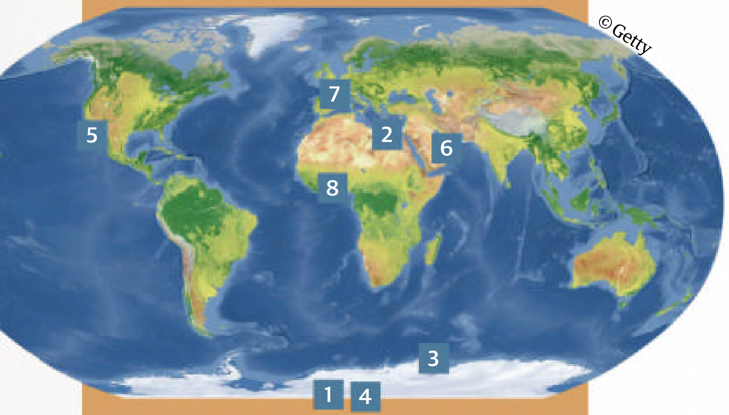
The first line of evidence was the presence of carbonate structures found along fissures and fractures, which have since been proven to have formed in the presence of liquid fluids - most likely water. The second line was the observation of mineralised, elongated structures that are associated with the carbonate structures resembling ancient bacterial life, which are known as 'biomorphs'. The third line was the detection of polycyclic aromatic hydrocarbons (PAHs), which are organic materials that are also found on Earth, and in the case of ALH84001 are thought to be fossils of a more complex bioorganic species. The last, but certainly not least, was the clear and unique population of the magnetite - a rock mineral made of iron and oxygen - crystals.

Sceptics have tried their best to disprove it, as they have every right to do. Many scientists claimed that some of the lines of evidence can be produced from abiotic (non-biological) processes, that they were created when preparing the sample or even contaminated during its time on Earth.

For instance, a lot of astronomers targeted the fourth line of evidence, the magnetite crystals. Many stated that these crystals were formed either by thermal decomposition or shock decomposition of iron-rich carbonate. Thomas-Keprta then went back to work and looked to strengthen their position, and did just that. "Given that, we argue that the results of our initial and subsequent peer-reviewed manuscripts remain valid. Perhaps the best way to illustrate this is by taking one of our key observations – for example, the presence of magnetite crystals embedded in ALH84001 carbonate," says Thomas-Keprta. "By eliminating the leading non-biologic hypotheses for the formation of the magnetites, our paper strengthens the original biologic hypothesis used to explain the unusual properties of ALH84001 carbonates and magnetites."

"The data presented by Thomas-Keprta and others on the unique magnetite crystals is the strongest supporting evidence for past biogenic activity within the ALH84001 meteorite," says Gibson. This lay the foundations for what would become decades of hunting for extraterrestrial life at its simplest form. "The Mars Exploration Rovers, Mars Reconnaissance Orbiter, Phoenix lander, Curiosity rover, the European Space Agency's Mars Express mission with its Beagle 2 Mars lander, along with the orbiters Maven, Mars Odyssey and so on, can all be traced to the ALH84001 research. The excitement of the possibility of potential past or present life on Mars is too important for humans to ignore," says Gibson.

NASA's astrobiology department was gaining momentum with repeated successful landings



©Getty

Martian meteorites found around the world

1. ALH84001
Allan Hills, Antarctica
27 December 1984
1.9 kilograms (4.3 pounds)

2. Nakhla
Abu Hummus, Beheira Governorate, Egypt
28 June 1911
Ten kilograms (22 pounds)

3. Yamato 00593
Yamato Glacier, Antarctica
December 2000
13.7 kilograms (30.2 pounds)

4. ALH77005
Allan Hills, Antarctica
29 December 1977
0.5 kilograms (1.1 pounds)

5. Los Angeles
Mojave Desert, California,
30 October 1999
0.7 kilograms (1.5 pounds)

6. Jiddat al-Harasis 479
Jiddat al-Harasis desert, Oman
2008
0.5 kilograms (1.1 pounds)

7. Chassigny
Chassigny, Haute-Marne, France
3 October 1815
Four kilograms (8.8 pounds)

8. Zagami
Zagami, Nigeria
3 October 1962
18 kilograms (40 pounds)

© NASA

and orbital insertions. All of these aforementioned missions and more have contributed to the cause, but no other mission has provided more valuable data in situ on Mars than the Mars Science Laboratory rover, or as it is more commonly known, the Curiosity rover. This rover's primary objective, even seven years after its landing, is to determine if Mars was once habitable, which has major implications for astrobiology. In fact, this branch of the space agency had a hand in Curiosity's design and helped in the development of onboard experiments, including the Sample Analysis at Mars (SAM) and Chemistry and Mineralogy (CheMin) instruments.

Since Curiosity's landing in August 2012, it has been exploring the Gale Crater, returning evidence of liquid water and what the Red Planet's geology and climate were like once upon a time. Curiosity has been one of the many missions that has cemented the theory that Mars was once a world where liquid water flowed on the surface, with a carbon dioxide-rich atmosphere that was capable of protecting its contents from harmful cosmic radiation. 3.6 billion years ago the Red Planet lost this atmosphere, and the planet went from wet and warm to dry and frosty.

In regards to ALH84001, Curiosity has been extremely helpful. In 2013 the rover was able to confirm that a number of Martian meteorites found on Earth were actually from Mars. This was achieved by measuring the element argon and defining its isotopes in the atmosphere using the SAM instrument. One result that is more curious, however, is the 'methane mystery'. Methane is a gas commonly found on Earth and is a known biosignature, or a by-product of life. After Curiosity detected methane in the atmosphere, the mystery about where it originated from prompted more research. Could it be from life?

Astronomers are aware that methane can also be created from abiotic processes, so no one is claiming that it must be life, but it is interesting enough to warrant further investigation. The exploration of Mars is far from done yet. The Red Planet will have several new visitors from a host of international space agencies in 2020, one of which is from NASA. It plans to launch a new rover based on Curiosity, with a similar look but an upgraded suite of instruments.

NASA's Mars 2020 rover is due to launch in either July or August 2020. After a seven-month journey through space – which is nothing compared to ALH84001's long voyage – it will touch down in the Jezero crater. From there Mars 2020 will provide a thorough remote analysis of the Martian surface with some instruments designed purely for astrobiology and the search for signs of life.

"Compared to Curiosity, the Mars 2020 rover will have improved autonomy, seven new science instruments and the ability to collect and seal samples and then set those samples aside to be collected during another mission," says Thomas-

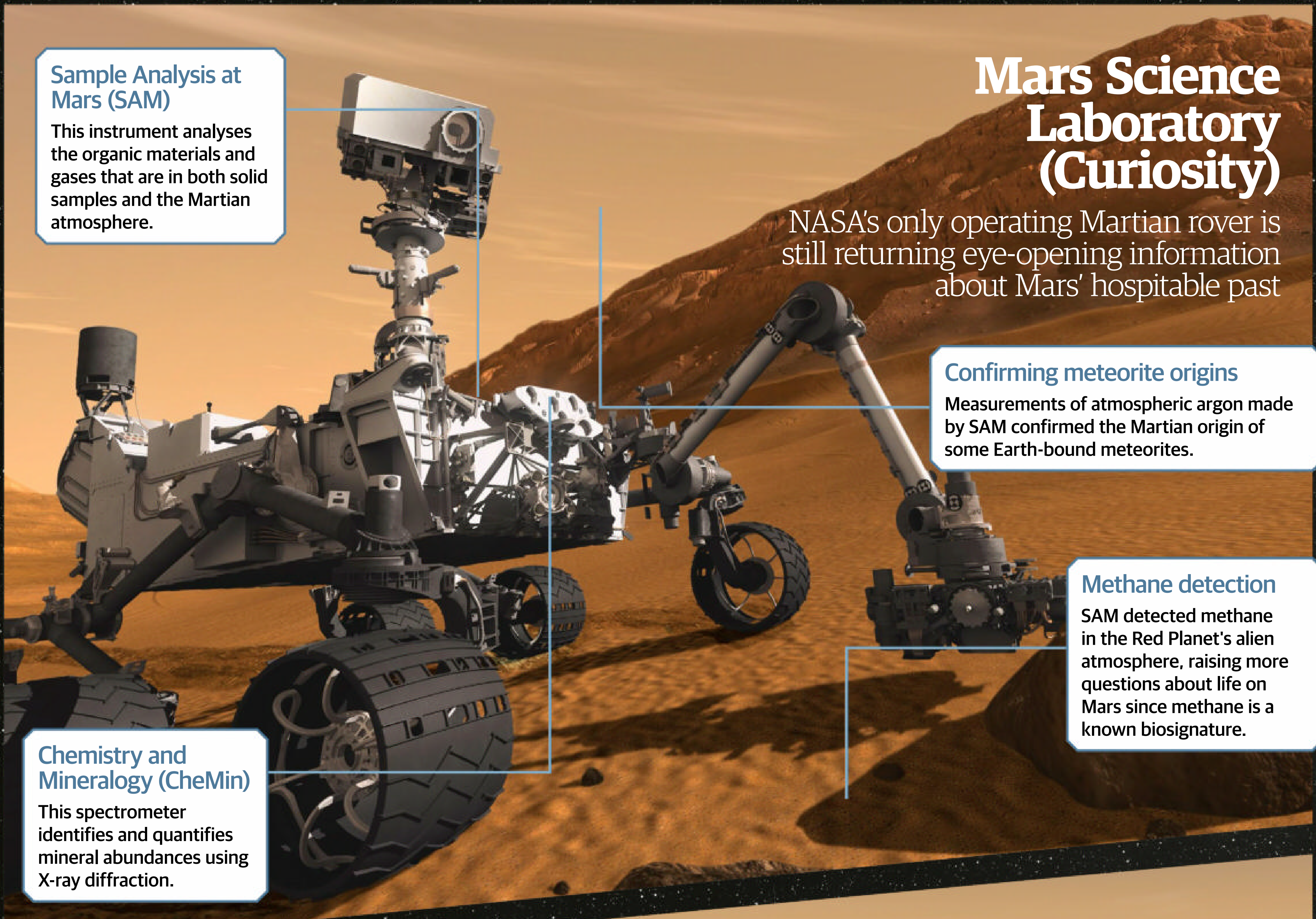
> "The excitement of the possibility of potential life on Mars is too important for humans to ignore" **Everett Gibson**

Below: ANSMET has been searching for meteorites in Antarctica since 1976

© Christine Floss

Mars Science Laboratory (Curiosity)

NASA's only operating Martian rover is still returning eye-opening information about Mars' hospitable past



Sample Analysis at Mars (SAM)

This instrument analyses the organic materials and gases that are in both solid samples and the Martian atmosphere.

Confirming meteorite origins

Measurements of atmospheric argon made by SAM confirmed the Martian origin of some Earth-bound meteorites.

Methane detection

SAM detected methane in the Red Planet's alien atmosphere, raising more questions about life on Mars since methane is a known biosignature.

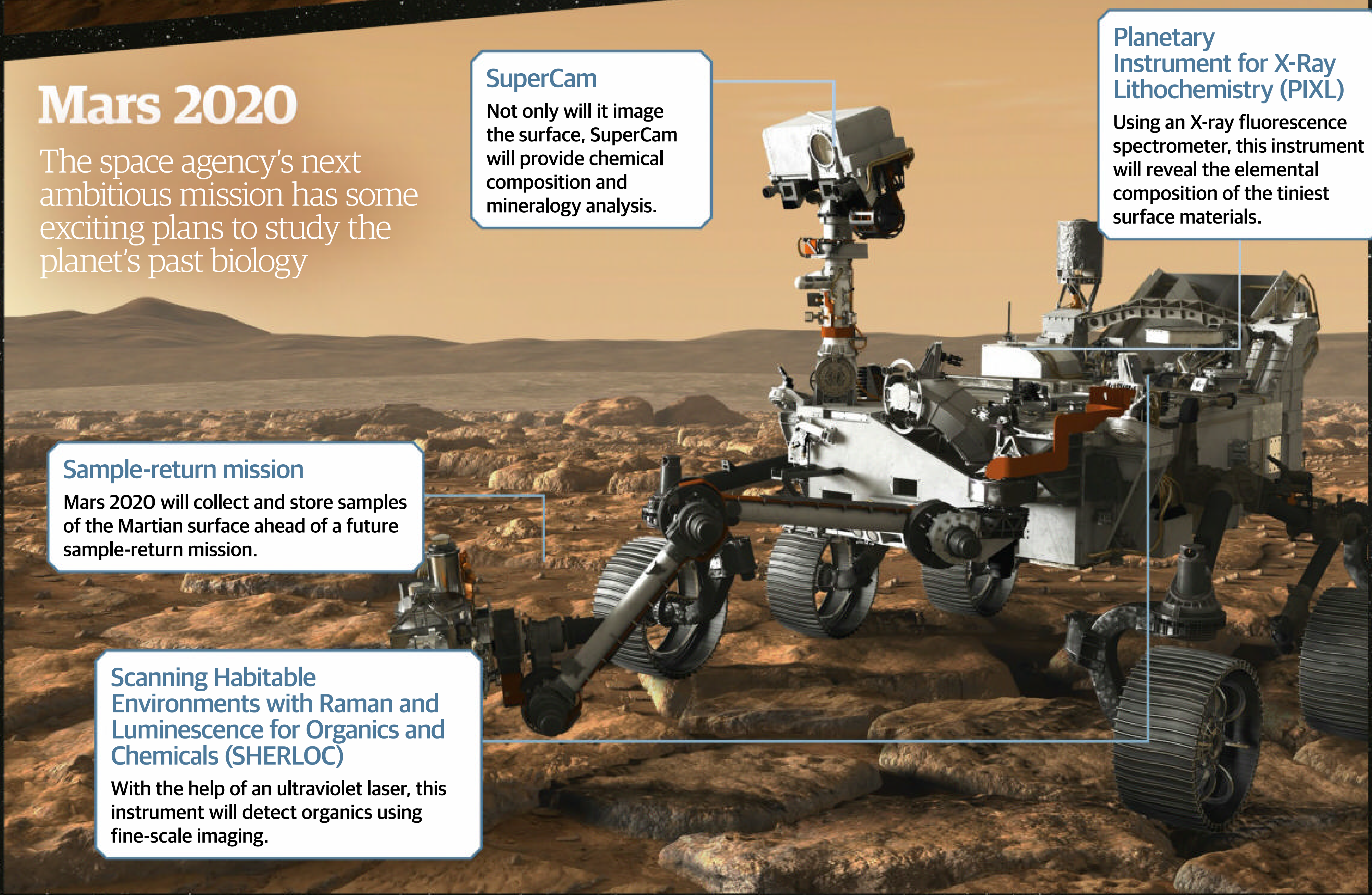
Chemistry and Mineralogy (CheMin)

This spectrometer identifies and quantifies mineral abundances using X-ray diffraction.

© NASA

Mars 2020

The space agency's next ambitious mission has some exciting plans to study the planet's past biology



SuperCam

Not only will it image the surface, SuperCam will provide chemical composition and mineralogy analysis.

Planetary Instrument for X-Ray Lithochemistry (PIXL)

Using an X-ray fluorescence spectrometer, this instrument will reveal the elemental composition of the tiniest surface materials.

Sample-return mission

Mars 2020 will collect and store samples of the Martian surface ahead of a future sample-return mission.

Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals (SHERLOC)

With the help of an ultraviolet laser, this instrument will detect organics using fine-scale imaging.

© NASA

Keprta. “While relying on heritage instrumentation from Curiosity, the science package is unique to the 2020 rover and includes instruments that will be used to acquire information about Martian geology, environmental conditions, atmosphere and possible biosignatures.

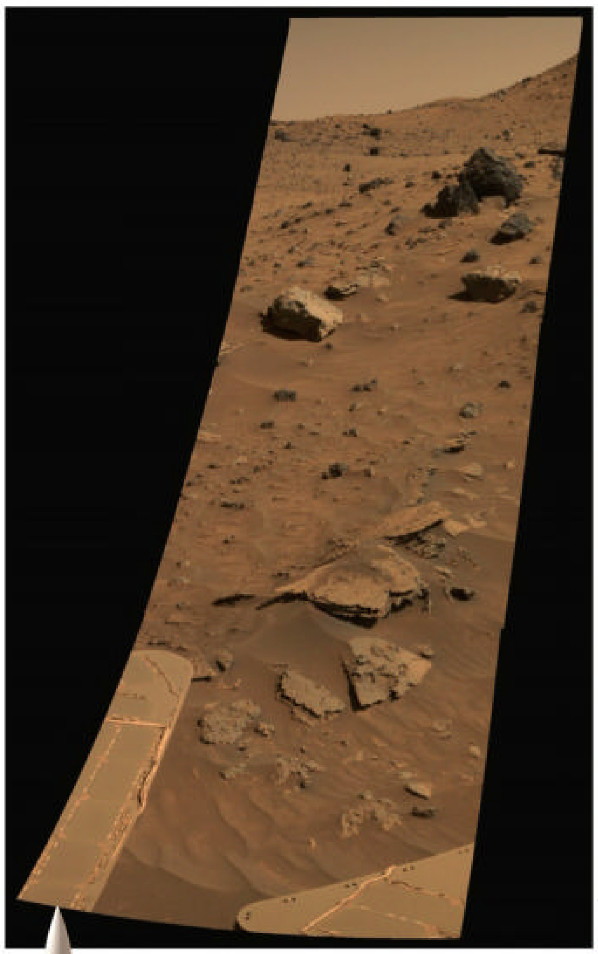
“Three of the science instruments have been developed to search for organic phases on Mars: the Planetary Instrument for X-ray Lithochemistry (PIXL), which can analyse and image grains as small as a grain of salt using X-ray fluorescence; the Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals (SHERLOC), which will use a UV laser to detect organic compounds and UV Raman spectrometry – the first of its kind to visit Mars – to identify mineral and organic phases and SuperCam, which will use a camera, lasers and spectrometers to search for and identify the chemical and mineral compositions of organic and mineral phases.”

Yet this cannot beat the analyses performed on Martian meteorites found on Earth. These invaluable samples have been delivered to locations all over the world, and groups such as the ANSMET team have been on the lookout for decades. As a result, more meteorites have been put under the microscope and have shown to enhance the ALH84001 team’s original stance, yet it is not enough.

“Research on additional Martian meteorites has shown that there is verification of indigenous organic materials within Martian materials,” says Gibson. “The four Martian meteorite samples – ALH84001, Nakhla, Yamato 00593 and ALH77005 – which have demonstrated signatures of past biogenic activity each have their problems – primary terrestrial contamination after falling on the Earth – which prohibit obtaining a definitive and detailed characterisation of the tantalising Martian biota.”

> “Mars 2020 will have improved autonomy, seven new instruments and the ability to collect and seal samples” **Kathie Thomas-Keprta**

Astronomers are now asking themselves what the next step is. How can they gain samples and data that can provide a clearer picture? The chances of finding a definitive answer are miniscule, as astronomers are essentially tasked with trying to go back in time billions of years and find signs of life. However, the next innovative plan is to collect a sample of Mars with the Mars 2020 rover and store it so later missions can jettison these samples back to Earth for further examination. A sample such as this would be priceless to the scientific community. With this plan in mind, it’s important to remember that ALH84001 was arguably the catalyst to all these amazing ideas, projects and exploration missions to Mars that are forcing everyone to face an extremely profound question: was, or is there still life on another planet?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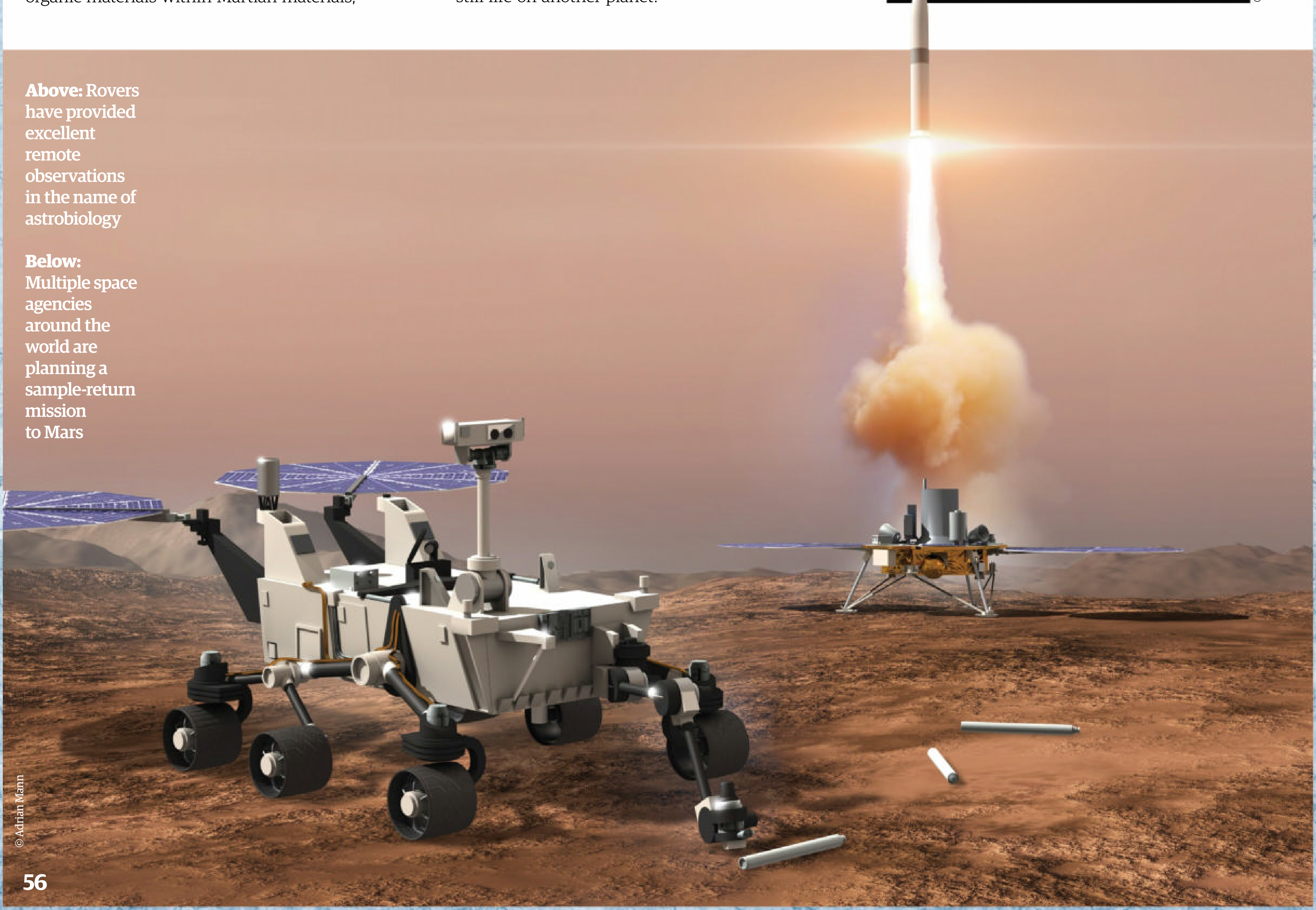

Above: Rovers have provided excellent remote observations in the name of astrobiology

Below: Multiple space agencies around the world are planning a sample-return mission to Mars

© Adrian Mann

APOLLO 11
50TH ANNIVERSARY
SPECIAL EDITION SPACE PENS

FISHER SPACE PEN CO.

Celebrate the most historic space event with these 50th Anniversary Apollo 11 Fisher Space Pens®. Each collectible pen is precision assembled and hand tested. All Fisher Space Pens® perform in extreme temperatures from (-30° to +250° F), at any angle – even upside down, underwater, in zero gravity, through grease and three times longer than the average pen.

Matte Black Bullet Space Pen
Moonscape Box Sleeve

When astronauts began to explore the reaches of outer space, Paul Fisher realized that there was no existing pen which could perform in its freezing cold, boiling hot vacuum. Countless experiments and a common-sense approach resulted in the invention of the sealed and pressurized ink cartridge and in 1967, after 18 months of rigorous testing by NASA, the Fisher Space Pen® was selected for use by the astronauts. It is still used today on all manned space flights.

Matte Black Bullet Space Pen
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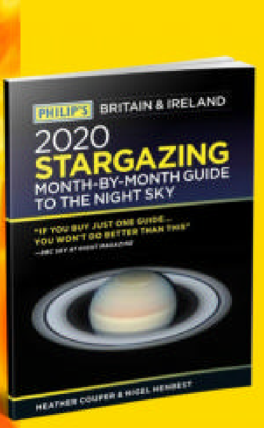
2020'S HOTTEST ASTRONOMY PRODUCTS


PHILIP'S BRITAIN & IRELAND
2020
STARGAZING
MONTH-BY-MONTH GUIDE TO THE NIGHT SKY
HEATHER COUPER & NIGEL HENBEST

All About Space's round-up of the telescopes, books and accessories guaranteed to enhance your views of the night sky throughout the new year

FirstScope Signature Series Moon by Robert Reeves

Cost: £59.00 (~€68.85/$76.30)

From: Celestron

1 Celestron has joined forces with master lunar imager Robert Reeves on this new addition to the beloved FirstScope family. This quality Dobsonian features a spherical glass mirror with a generous 76mm of aperture. The FirstScope's wide field of view provides bright, sharp views of the Moon's mountains and craters in crisp detail. You'll also enjoy using the FirstScope to pan the Milky Way, explore open star clusters, marvel at Saturn's rings or view favourite deep-sky objects like the Orion Nebula. This compact, lightweight telescope is an ideal entry-level astronomical telescope.

Nirvana-ES UWA-82°

Cost: From £79.99 (~€93.30/$103.40)

From: opticalvision.co.uk

2 These top-quality ultra-wide-angle 1.25-inch eyepieces offer an incredible viewing experience, but at an extremely competitive price. The huge 82-degree apparent field of view, superb field-edge correction and excellent contrast combine to provide a wonderfully immersive and memorable viewing experience. They work superbly in telescopes of all focal lengths. These exotic eyepiece models feature large eye-lens elements and soft fold-down rubber eyecups for comfortable viewing. All models are fully broadband multi-coated, feature blackened lens edges and internal baffling and are parfocal.

Tele Vue Optics Bandmate Filters

Cost: £80.00 (~€93.30/$103.40)

From: televue.com

3 Tele Vue Optics teams up with filter manufacturer Astronomik to revamp its series of nebula filters for deep-sky observing, offered in three select passbands: H-beta, OIII and the Nebustar, a unique ultra-high contrast (UHC) filter that peaks at both H-beta and OIII wavelengths. Unlike other UHC filter designs the Nebustar passband blocks redder wavelengths, producing sharper, more natural-looking stars while enhancing sought-after nebulosity. All three models are offered in 1.25-inch and two-inch format. Each filter is manufactured in Germany by Astronomik and optically tested by Tele Vue, and includes a ten-year warranty.

Celestron Advanced VX 800 Rowe-Ackermann Schmidt Astrograph (RASA) telescope

Cost: £2,788.00 (~€3,250.00/$3,600.00)

From: Celestron

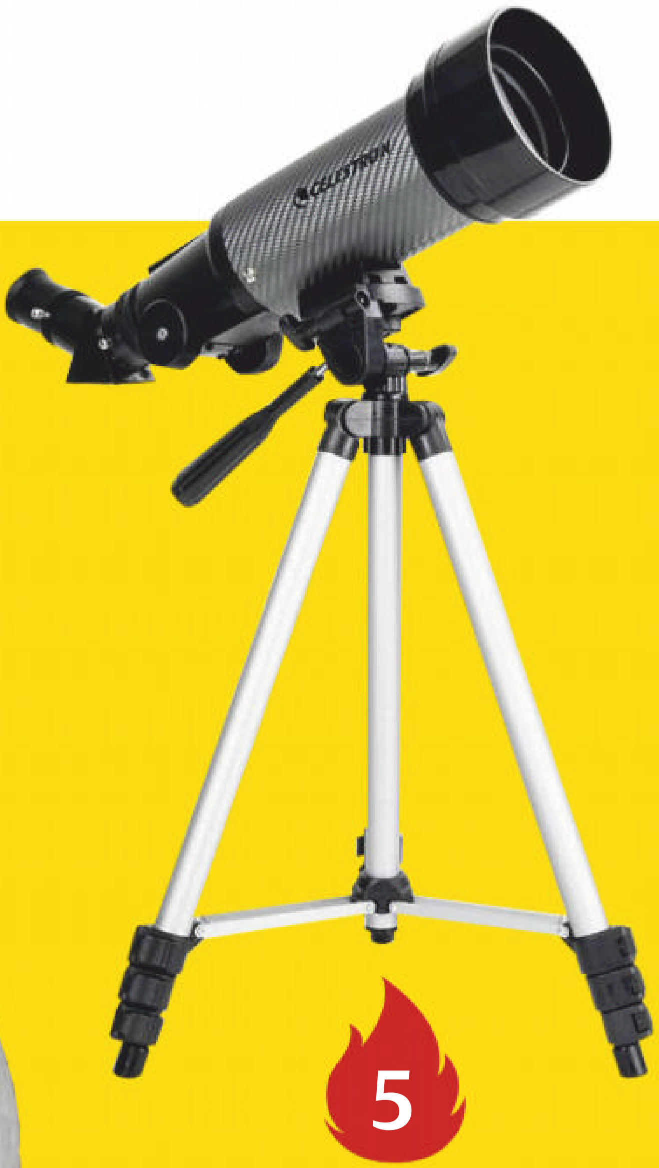
4 Capture spectacular wide-field deep-sky images in seconds with Celestron's new portable astrograph. This incredibly fast f/2.0 system is the perfect companion to today's colour astronomical CMOS cameras, smaller CCD cameras, and mirrorless cameras. Thanks to its fast focal ratio and patented optical design, you can produce sharp, detailed images and, in many cases, skip the autoguider completely. Weighing in at just 7.7 kilograms (17 pounds), it's easy to transport your RASA to the most remote dark-sky locations.

Celestron Travel Scope 70 DX Portable Telescope

Cost: £89.00 (~€103.80/$115.00)

From: Celestron

5 Get a new perspective on nature and the universe with the ideal day-to-night telescope, the Travel Scope 70 DX. This refractor telescope includes a full-height tripod and lots of bonus accessories, including a smartphone adapter so you can capture images and video through the eyepiece. It all packs up into a high-quality custom backpack, ready to go wherever your adventures take you. By night the 70 DX delivers great views of the planets, the Moon, star clusters and brighter deep-sky objects like the Orion Nebula and Andromeda Galaxy. During the day the 70 DX doubles as a spotting scope.

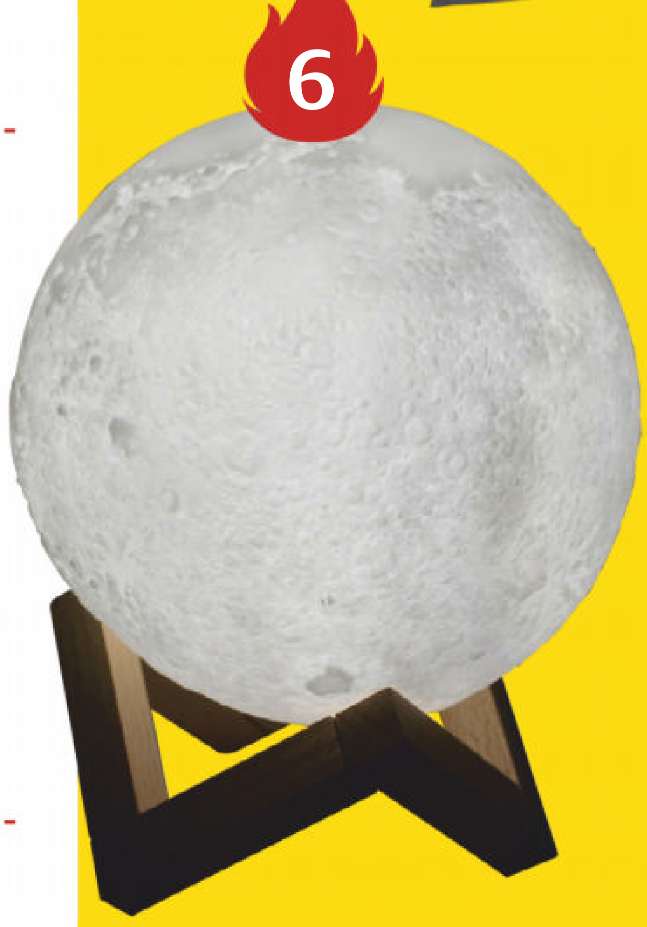


National Geographic Moon Lamp

Cost: £17.00 (~€19.80/$21.95)

From: Telescope House

6 It's over 50 years since man first walked on the Moon, and our nearest celestial neighbour is just as mysterious and fascinating as ever. This delightful night light from National Geographic is a miniature model of the Moon and provides gentle light for a child's bedroom or to set the scene for the grown-ups in the house. The National Geographic 3D Moon Lamp with Stand is charged by USB, and a single charge will give up to six hours of light. You can choose between cool blue-tinted light or a warmer yellow, depending on your mood. It comes complete with a stylish wooden stand for stability and a USB charging cable.



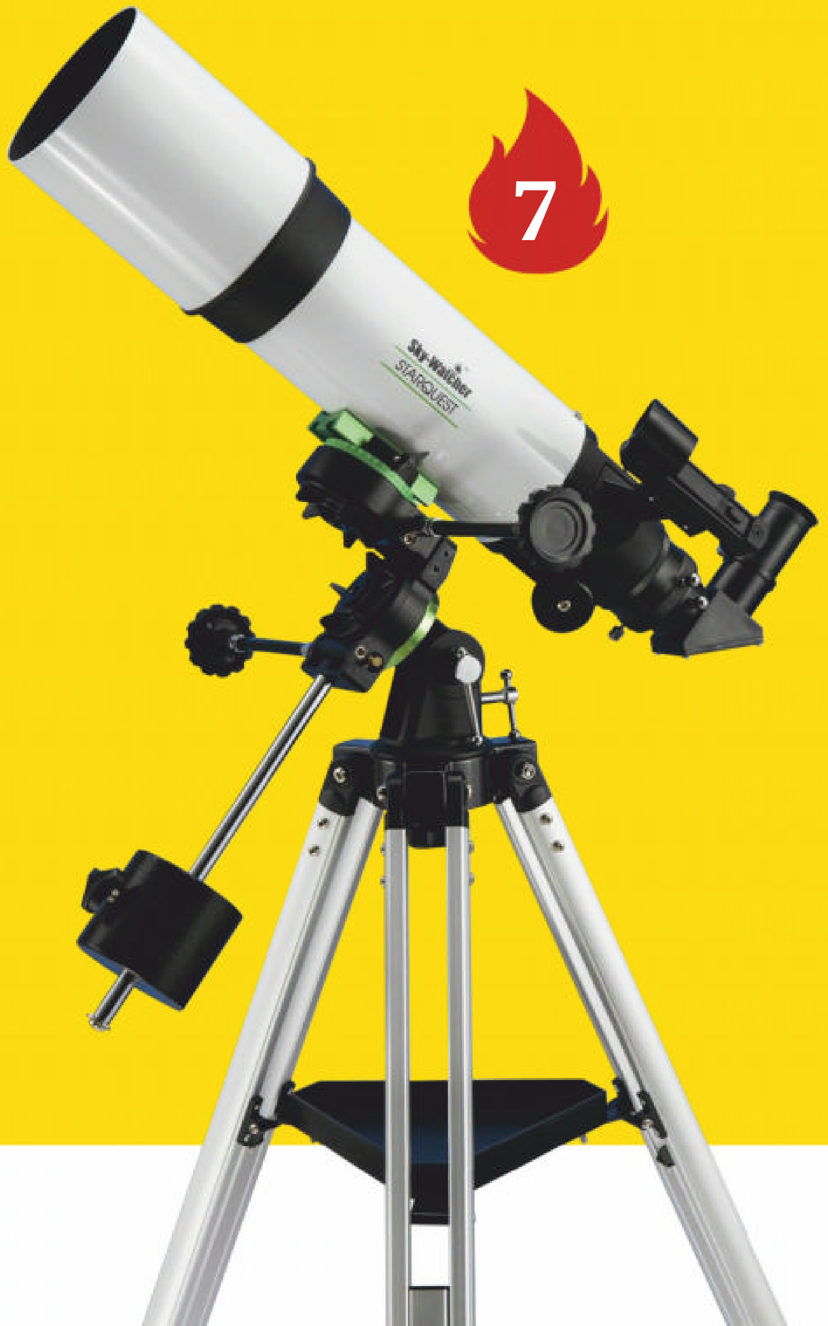
Sky-Watcher Starquest-102R

Cost: £249.00 (~€290.40/$321.60)

From: opticalvision.co.uk

7 The StarQuest series is a lightweight, 'grab-and-go' range combining proven high-quality Sky-Watcher telescope optics with a newly designed and well-engineered equatorial mount. The equatorial mount, when polar aligned, allows you to easily track objects as they move across the night sky with its smoothly operated slow-motion control cables. The StarQuest-102R is a two-element, air-spaced achromatic refractor telescope package, and a well-proven performer for 'rich-field' views of comets, star fields, star clusters, nebulae, bright galaxies and planets and the Moon. Supplied complete with mount and aluminium tripod.

> "The StarQuest series is a lightweight, 'grab-and-go' range"

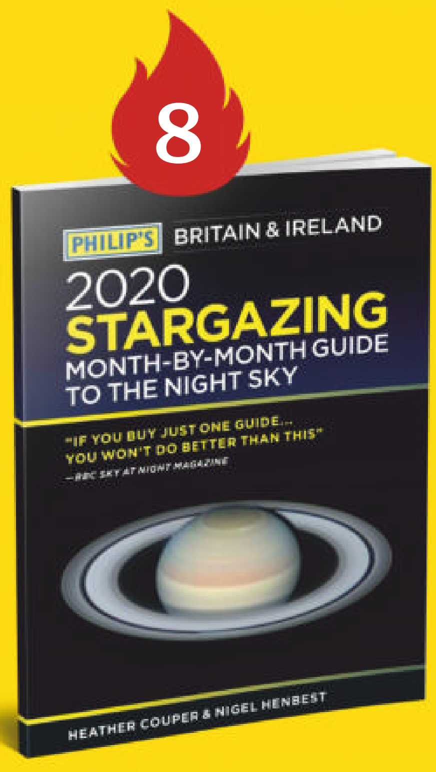


Philip's 2020 Stargazing Month-by-Month Guide to the Night Sky

Cost: £6.99 (~€8.15/$9.00)

From: Philip's

8 The new 2020 edition has been revised to make it even more essential for exploring the night skies, featuring 12 monthly night-sky maps, monthly calendar of Moon phases and special events in 2020, advice on best planetary viewing and much more. Essential reading for astronomers at all levels, it's written by two of the UK's best-known and respected astronomers. Professor Heather Couper is an internationally acclaimed astronomer, and Professor Nigel Henbest has been a consultant to the Royal Greenwich Observatory.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PHILIP'S
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TO THE NIGHT SKY
"IF YOU BUY JUST ONE GUIDE... YOU WON'T DO BETTER THAN THIS"
—BBC SKY AT NIGHT MAGAZINE
HEATHER COUPER & NIGEL HENBEST

Orion CC8 8" f/12 Classical Cassegrain Telescope

Cost: £949.99 (~€1,108.60/$1,227.50)

From: Orion Telescopes

9 The 8" f/12 Classical Cassegrain Telescope excels for high-resolution lunar and planetary viewing and imaging, and will get you in close on tight deep-sky objects such as globular clusters and planetary nebulae. In a telescope market currently saturated with short-focal-length, wide-field instruments, the CC8 stands apart by offering something for those wanting serious magnifying capability but in a compact form. With an optional 10mm eyepiece you're already probing at 240x magnification! There is no pesky chromatic aberration since there are no lenses as in a refractor.

Celestron Nature DX ED 10x42 binoculars

Cost: £219.00 (~€255.50/$282.80)

From: Celestron

10 Celestron's award-winning Nature DX binocular gets a major upgrade with the addition of ED objective lenses. Nature DX ED's optical performance rivals that of more expensive binoculars at a price to fit your budget. This versatile, all-round binocular is a great choice for the trail, the arena, the night sky or just about anywhere you want a close-up view of the action without sacrificing brightness or detail. It's an especially great companion for nature observation and bird watching, with ED glass that helps you spot the subtlest field markings and a close focus of 1.9 metres (6.5 feet).

MallinCam SkyRaider DS10c live-view camera

Cost: £720.00 (~€839.95/$929.99)

From: MallinCam

11 The SkyRaider DS10c is built around hand-selected Sony IMX294 back-illuminated colour CMOS industrial sensors. The camera uses four gigabits DDR internal memory and can be operated in either 8- or 12-bit mode with several binning options. It connects to most telescopes with an included T-adapter or two-inch nosepiece. The DS10c connects to your PC via a USB 3.0 interface and can output single FITS, JPEG, BMP, or PNG files, or AVI and SER video formats. The unit can also operate as an autoguider that connects to your mount via an RJ-11 port.

Orion SpaceProbe II 76mm Equatorial Reflector Telescope

Cost: £101.99 (~€119.00/$131.75)

From: Orion Telescopes

12 Great for all-round astronomical observing, the affordable Orion SpaceProbe II is just the right size and price for beginning astronomers and their families. The SpaceProbe II gathers a good amount of light from the night sky for impressively bright and detailed views of celestial wonders. Everyone in the family will want to join the fun for great views of the Moon, bright planets and star clusters seen through the telescope. This complete, full-fledged reflector telescope will help foster a lifetime of appreciation for science and astronomy.

Meade StarPro AZ

Cost: £99.95 (~€116.60/$129.00)
From: Meade Instruments

13 Meade's StarPro AZ is the perfect 'scope for the novice astronomer seeking to explore the universe! The StarPro AZ series features refracting telescopes that are available in four different apertures: 70mm, 80mm, 90mm and 102mm. The StarPro AZ features a newly designed single-arm, alt-azimuth mount with slow-motion control cables on both axes. This new mount includes a Vixen-style dovetail receiver, giving you the ability to switch out a variety of different optical tubes to your liking. Also, each optical tube offered with the StarPro AZ includes fully coated optics, resulting in bright, clear images of the Moon, planets, nebulae and more!

Celestron NexYZ smartphone adapter

Cost: £38.99 (~€45.50/$50.35)
From: f1telescopes.co.uk

14 This unit allows you to use almost any smartphone camera to capture the brighter Solar System objects and even some deep-sky targets. Its spring-loaded clamp and innovative three-axis adjustments permit you to place your device's camera perfectly against virtually any eyepiece on a telescope, binocular or microscope quickly and precisely. The NexYZ attaches securely to any eyepiece from 35 to 60mm in diameter with a padded clamp and adjustable safety lock. Two additional adapter rings are included for connecting the device to smaller microscope eyepieces.

Orion GoScope 80mm Backpack Refractor Telescope

Cost: £179.99 (~€209.95/$232.40)
From: Orion Telescopes

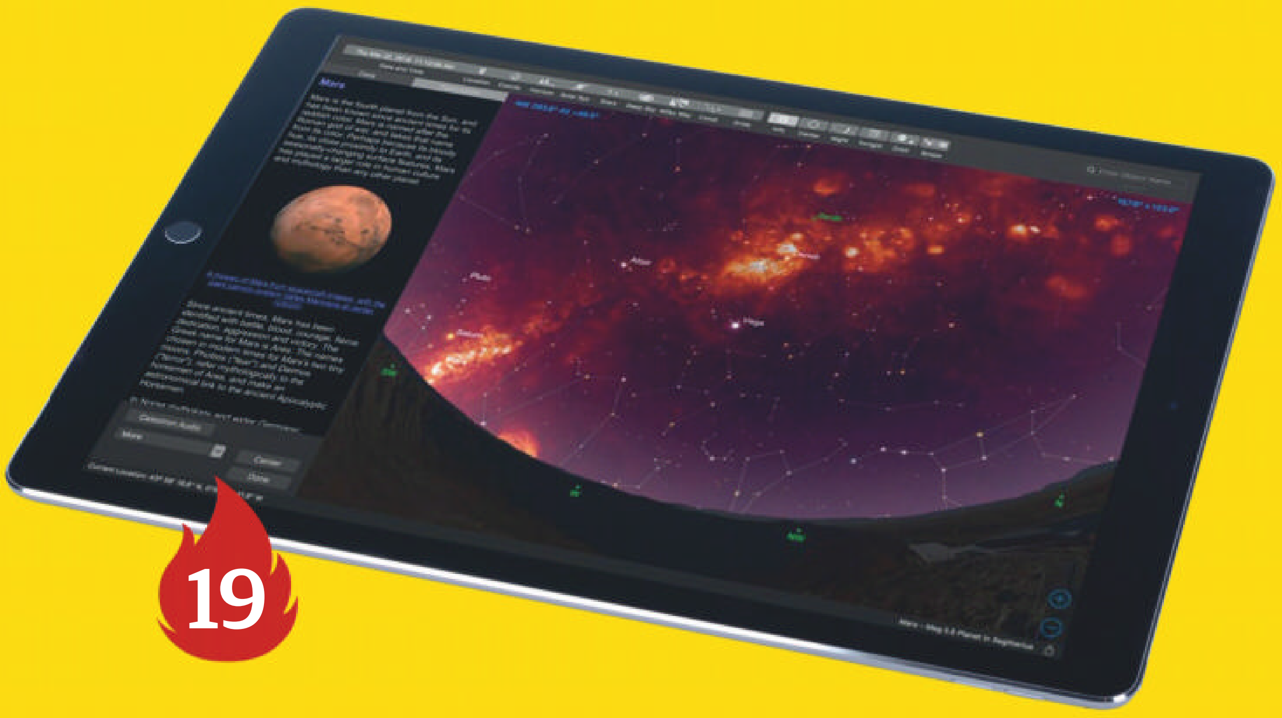
15 The GoScope is a versatile wide-field refractor with a full-length photo-type tripod, plus all the accessories you need to observe wildlife, the Moon or nebulae. All of it fits neatly in the included padded backpack with adjustable shoulder straps for carrying comfortably to your observing spot. The affordable GoScope features a fully antireflection-coated 80mm achromatic lens system with a 400mm focal length (f/5) for vivid images of distant subjects in a wide field of view. The 1.25" rack-and-pinion focuser ensures your observing target will snap into sharp focus effortlessly.

QHYCCD cooled CMOS

Cost: £3,435.00 (~€4,008.40/$4,434.90)
From: qhyccd.com

16 A 14-bit, full-frame CMOS camera for deep-sky astrophotography, the camera is designed around the Sony colour CMOS IMX094 sensor. The unit is capable of recording 3.2 full-resolution frames per second, and even faster rates when using on-chip region of interest. An internal 128-megabyte DDRII image buffer ensures no frames are dropped during downloads. Each camera comes with a one-metre (3.2-foot) 12V threaded power cord, a 1.5-metre (4.9-foot) USB 3.0 cable and a two-inch nosepiece, plus a CD with camera drivers and control software.

> "Each optical tube offered with the StarPro AZ includes fully coated optics"



Meade Instruments LPI-G Advanced Camera (Monochrome)

Cost: £310.00 (~€361.80/$400.20)
From: Meade Instruments

17 This USB 3.0 14-bit camera allows for increased dynamic range, allowing the user to experience the universe like never before! The LPI-G Advanced features a large image sensor along with a high pixel count that allows for increased resolution, making it ideal for planetary and solar imaging. Able to take 59 frames per second at full resolution, the LPI-G Advanced is able to save images in a variety of formats including JPEG, BITMAP, FITS, TIFF, PNG, PCX, TGA and BCM. It can also save videos in either SER or AVI formats.

Vaonis AP 80/400 STELLINA

Cost: £3,430.00 (~€4,003.40/$4,430.60)
From: astroshop.eu

18 The Vaonis STELLINA smart telescope allows observations of the Moon, galaxies, nebulae and comets - fully automated and convenient from your smartphone or tablet. Traditional telescopes show faint deep-sky objects only as hazy glowing clouds. This is especially frustrating in light-polluted areas around towns and cities. Long exposures through an astrophotography camera need to replace the human eye to show more details and colours. STELLINA reveals these faint features with unprecedented ease of use. This smart telescope is a fully automated astrophotography rig.

SkySafari 6 Pro

Cost: £2.29 (~€2.70/$2.95)
From: simulationcurriculum.com

19 One of the most popular planetarium apps for Apple devices gets a big update. Among its many new functions are a 'Say It' feature that incorporates basic voice control to find and centre objects, and 'Tilt It', which uses your device's accelerometers to slew your Go-To telescope. SkySafari 6 includes 29 million stars down to 15th magnitude and the PGC catalogue including 784,000 galaxies to 18th magnitude. Each of the stellar and deep-sky object catalogues is expandable with in-app purchases. Available in Basic, Plus and Pro versions, each requires iOS 8 or later. An Android version is also available.

Stellarvue's Optimus wide-field eyepieces

Cost: £270.00 (~€315.00/$348.75)
From: stellarvue.com

20 Stellarvue announces an expansion of its Optimus line of 100-degree eyepieces. The new 13.5mm Optimus 1.25-inch eyepiece fills the void between its 9 and 20mm offerings, adding additional versatility to the series. The ocular is sealed to prevent moisture between glass elements, and it features broadband multi-coatings on all surfaces to virtually eliminate internal reflections. The 13.5mm Optimus includes extra-durable rubber eyeguards and a precision-machined 1.5-to-two-inch focuser adapter.

MISSION PROFILE

InSight

NASA's latest Martian lander has been busy learning about the secrets that are buried beneath the Red Planet

Mission type
Lander
Operator
NASA
Launch date
5 May 2018
Target
Mars
Arrival at target
26 November 2018
Primary objective
Study Mars' interior to understand its formation
Status
Active

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Dr William "Bruce" Banerdt
Principal investigator for the InSight mission
Bruce Banerdt is the head of scientific operations for the InSight lander and is situated at NASA's Jet Propulsion Laboratory in Pasadena, California. His previous work includes other Mars missions such as the Mars Exploration Rover project, the Mars Global Surveyor and the Magellan mission.

NASA's Interior Exploration using Seismic Investigations, Geodesy and Heat Transport, or InSight for short, was one of the major launches of 2018, signifying the 12th instalment in the agency's Discovery Program. This programme is focused on exploring the unknown and pondering one of life's greatest questions: how did we get here? InSight is a unique mission to Mars which is designed to decipher the inner workings of the Red Planet, including any seismic or molten activity, in an attempt to understand the planet's formation. By understanding more about how Mars formed over 4 billion years ago, scientists can apply this knowledge to all of the Solar System's inner planets, including Mercury, Venus and, more importantly, Earth.

The principal investigator of the InSight mission, Bruce Banerdt, summarises the objectives to **All About Space** as the following: "The objectives of the mission are to map the structure and thermal state of the deep interior of Mars for the first time, and to use this information to better understand the early formation processes of terrestrial planets, including the Earth."

In order to do so, the Martian lander was built to land safely on the surface and then unsheathe a unique suite of instruments to probe underneath the surface. InSight has reused technologies and designs from a previous NASA Martian lander, Phoenix, which successfully landed on the Red Planet in 2008. Ten years on and NASA ramped it up in order to perform a very different task, but Banerdt says that using the same design gave them "proven landing and surface systems without the cost of developing them from scratch".

The mission was launched on 5 May 2018 on the top of an Atlas V rocket from the United States' Vandenberg Air Force Base in California. It was launched alongside NASA's Mars Cube One (MarCO) cubesats, which travelled with InSight and relayed real-time communications with Earth during the lander's entry, descent and landing. This occurred on 26 November 2018 at Elysium Planitia.

InSight touched down safely after what is referred to by many engineers and astronomers as the 'six minutes of terror', so-called because they have to slow down a spacecraft travelling at 19,794 kilometres (12,300 miles) per hour to a complete stop without crashing it. To the relief of everyone on the ground, InSight reported back safe and sound, meaning the team could move onto the next process, which was unpacking its instrumental suite.

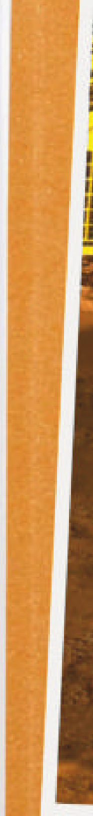
InSight has three main instruments in its suite, along with cameras, a magnetometer and several types of sensors. The first of its suite to be unpacked and placed onto the Martian surface by its robotic arm was the Seismic Experiment for Interior Structure (SEIS) instrument. According to Banerdt, SEIS "will 'listen' for the small [fractions of a nanometre] ground vibrations due to seismic waves that have travelled through the planet from distant marsquakes. Analysis of these waves will allow us to create a 3D picture of the inside of the planet."

Next, InSight used its robotic arm to place the Heat Flow and Physical Properties Package, or HP^3, which will pierce almost five metres (16 feet) into the rocky surface. "Temperature sensors on its trailing cable will measure the slight increase of temperature with depth, which will allow us to determine the amount of heat escaping from the planet" explains Banerdt. "This gives us a measure of the strength of the planetary heat engine that drives geologic processes on Mars."

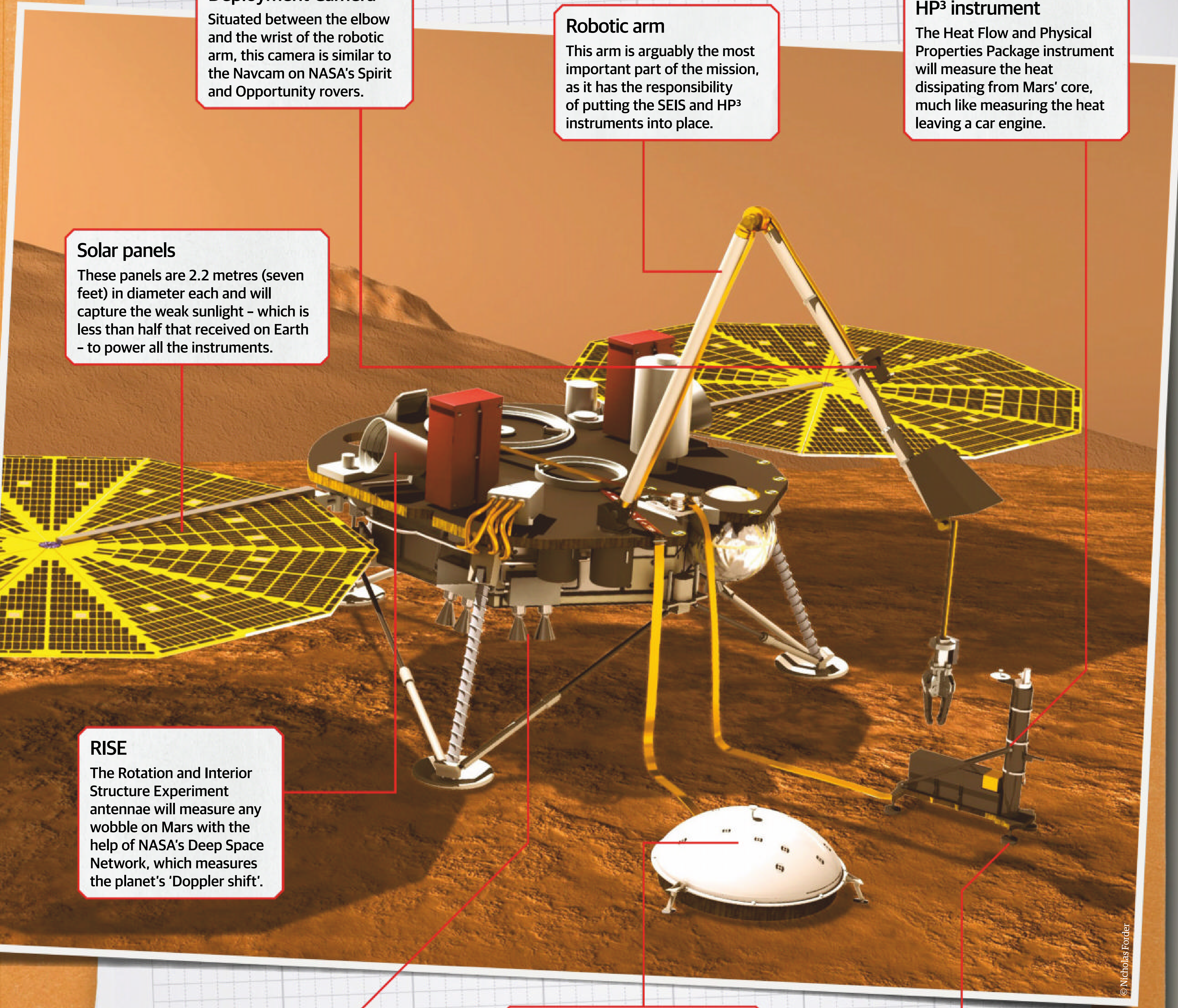
> "Analysis of these waves will allow us to create a 3D picture of the inside of the planet" **Bruce Banerdt**

The last piece of the trinity is built into the lander itself, so it doesn't require the same robotic arm attention. This is the Rotation and Interior Structure Experiment, or RISE. "RISE will use the X-band radio system on the lander to work with [NASA's] Deep Space Network dishes on Earth to track the location of the lander to an accuracy of a handful of centimetres for about an hour each day," says Banerdt. "This is enough to determine the direction of Mars' rotation pole and any wobble that it exhibits. This wobble is connected to the properties of the core, and will yield its size and density - which is related to its elemental composition."

Banerdt also explains that this mission has the potential to operate for a longer duration beyond the predicted lifetime, just like its Martian predecessors. "Our primary mission is planned for two [Earth] years - one Mars year," he explains. "However, we don't have any consumables that would limit the life of the lander. If we are lucky, we could last many years, like several of the Mars rovers before us."



Some insight into InSight



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Instrument Deployment Camera

Situated between the elbow and the wrist of the robotic arm, this camera is similar to the Navcam on NASA's Spirit and Opportunity rovers.

Robotic arm

This arm is arguably the most important part of the mission, as it has the responsibility of putting the SEIS and HP^3 instruments into place.

HP^3 instrument

The Heat Flow and Physical Properties Package instrument will measure the heat dissipating from Mars' core, much like measuring the heat leaving a car engine.

Solar panels

These panels are 2.2 metres (seven feet) in diameter each and will capture the weak sunlight – which is less than half that received on Earth – to power all the instruments.

RISE

The Rotation and Interior Structure Experiment antennae will measure any wobble on Mars with the help of NASA's Deep Space Network, which measures the planet's 'Doppler shift'.

Instrument Context Camera

The ICC is mounted just below Insight's deck and provides a 120-degree, wide-angle view of the entire workspace.

SEIS

Under the wind and thermal shield is the Seismic Experiment for Interior Structure – the first seismometer on another planet – which 'listens' to the planet's vibrations.

Heat flow probe

Nicknamed 'the mole', this instrument is intended to dig down five metres (16 feet) into Mars so it remains unaffected by changes in the seasons.

MISSION PROFILE

Progress report

We're nearing the first anniversary of the InSight lander's arrival at Mars, so what has it achieved in the last year? Well, it's been rather fruitful. The SEIS instrument was the first to be placed onto the surface by the robotic arm, and this has since picked up several vibrations that have given the team the first evidence of marsquakes. The first of these was announced on 23 April 2019, and Banerdt said at the time: "InSight's first readings carry on the science that began with NASA's Apollo missions. This first event officially kicks off a new field: Martian seismology!"

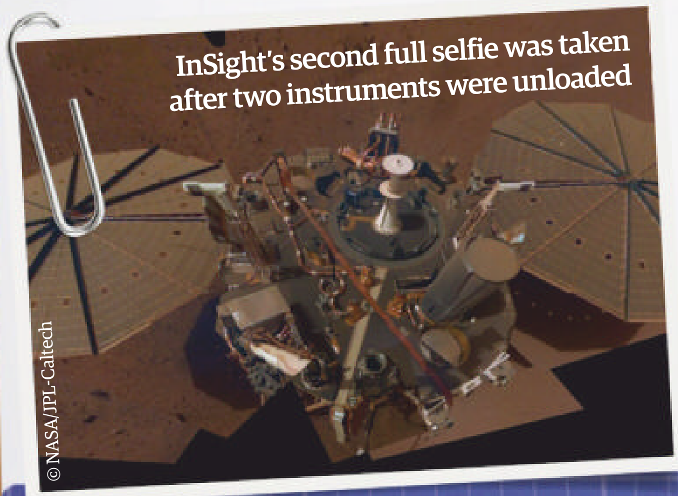
Next was the deployment of the heat probe, but the team hit a wall - well, more of a rock. The burrowing section of HP³, referred to as 'the mole', found itself unable to dig further than 0.3 metres (one foot). The InSight team even resorted to the old-fashioned tactic of hammering it, doing so 220 times over a nine-day period in October 2019. At the time of writing the probe has moved slightly over a couple of centimetres, but nowhere near the intended five metres (16 feet) in order to probe the interior heat of the planet.

However, this is not something to look at as a complete negative. There are definitely positives buried deep down in this situation. For instance, this inability to dig deeper than scientists thought must mean there is a different soil resting under the surface. This is an intriguing aspect that warrants future investigation.

Back on Earth, InSight has crossed paths with the celebrity world. In August 2019, Robert Downey Jr went on stage at a Rolling Stones concert in Pasadena, California, and announced that there is a rock on Mars, sent rolling by the lander's thrusters upon descent, which has been renamed the 'Rolling Stones Rock', bringing a whole new meaning to the term 'rock and roll'!

An artist's impression of InSight touching down on Mars

© NASA/JPL-Caltech

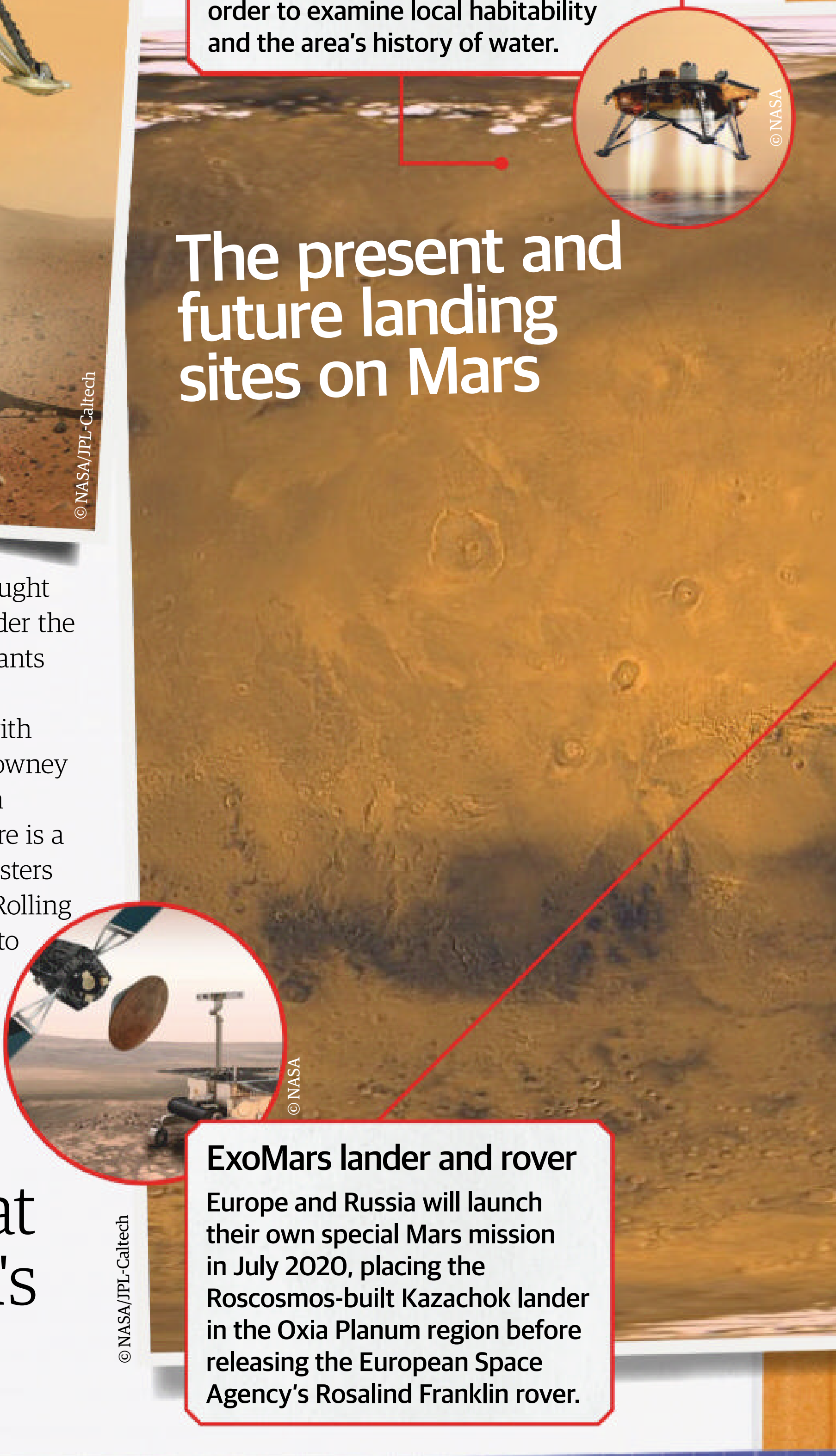

InSight's second full selfie was taken after two instruments were unloaded

© NASA/JPL-Caltech

> "InSight's first readings carry on the science that began with NASA's Apollo missions"
>
> **Bruce Banerdt**

© NASA/JPL-Caltech

The present and future landing sites on Mars



Phoenix lander

InSight's predecessor, Phoenix, landed in the northern-latitude region of Vastitas Borealis on 25 May 2008 in order to examine local habitability and the area's history of water.

© NASA

ExoMars lander and rover

Europe and Russia will launch their own special Mars mission in July 2020, placing the Roscosmos-built Kazachok lander in the Oxia Planum region before releasing the European Space Agency's Rosalind Franklin rover.

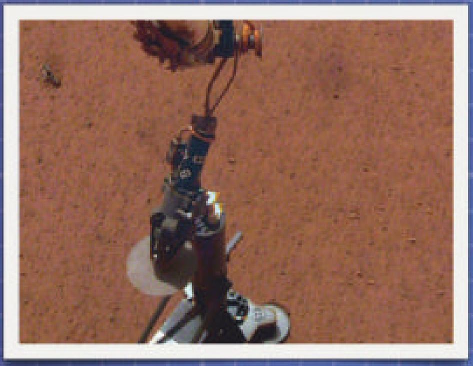
© NASA

Shifting the problematic mole

HP³ deployment

12 February 2019

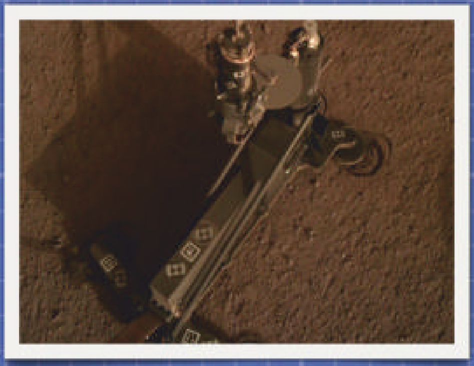
HP³ was deployed roughly one metre (three feet) from the SEIS instrument ahead of measuring Mars' temperature with the self-hammering 40-centimetre (16-inch) long 'mole'.



Hitting the wall

28 February 2019

Under the HP³ support stand, the mole struggled to fully evacuate the support instrument before hitting a tough patch. This began the problem of shifting it through alien terrain.



Hammering the mole

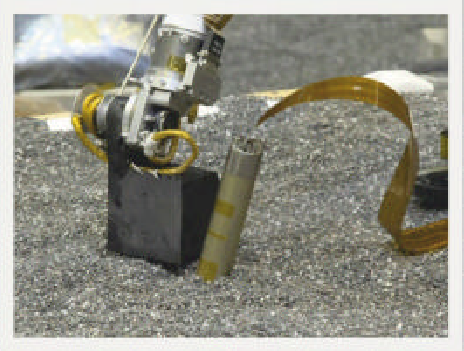
11 April 2019

With help from the SEIS instrument, the team began hammering the mole while listening to the seismic activity to help define the object that is blocking the heat probe's path.

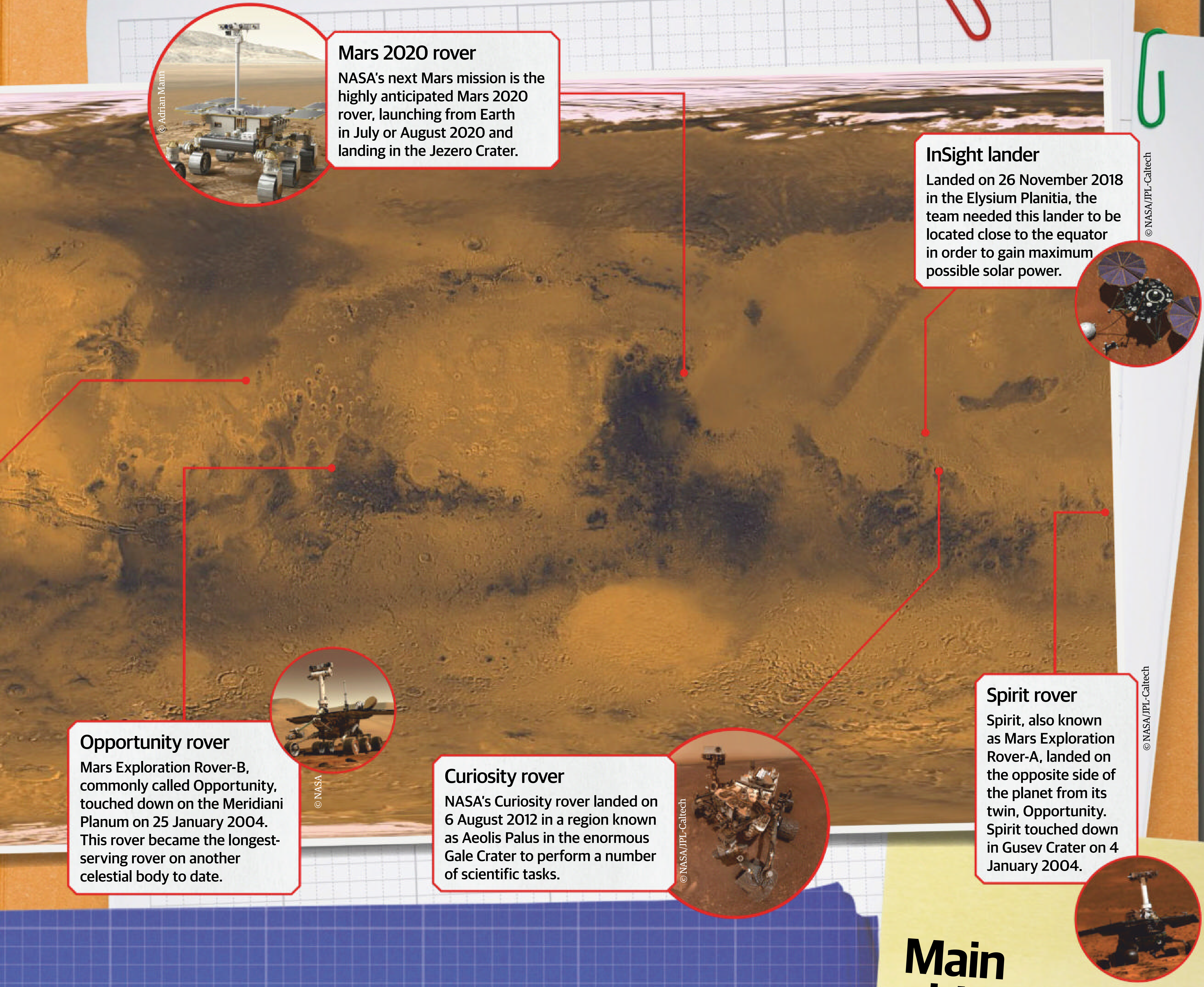
Developing a new tactic

5 June 2019

Earth-based tests were of top priority as the InSight team replicated the conditions on Mars in order to come up with a plan to get the mole moving again.



x7 images © NASA/JPL-Caltech



© Adrian Mann

Mars 2020 rover

NASA's next Mars mission is the highly anticipated Mars 2020 rover, launching from Earth in July or August 2020 and landing in the Jezero Crater.

InSight lander

Landed on 26 November 2018 in the Elysium Planitia, the team needed this lander to be located close to the equator in order to gain maximum possible solar power.

© NASA/JPL-Caltech

Opportunity rover

Mars Exploration Rover-B, commonly called Opportunity, touched down on the Meridiani Planum on 25 January 2004. This rover became the longest-serving rover on another celestial body to date.

© NASA

Curiosity rover

NASA's Curiosity rover landed on 6 August 2012 in a region known as Aeolis Palus in the enormous Gale Crater to perform a number of scientific tasks.

© NASA/JPL-Caltech

Spirit rover

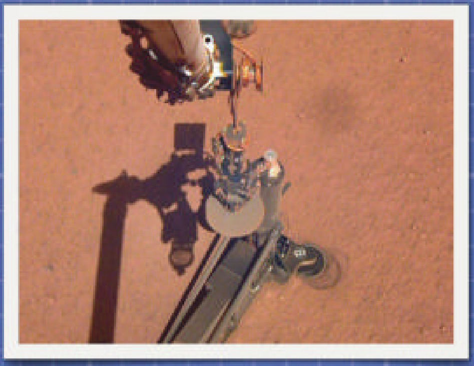
Spirit, also known as Mars Exploration Rover-A, landed on the opposite side of the planet from its twin, Opportunity. Spirit touched down in Gusev Crater on 4 January 2004.

© NASA/JPL-Caltech

Removing the support instruments

28 June 2019

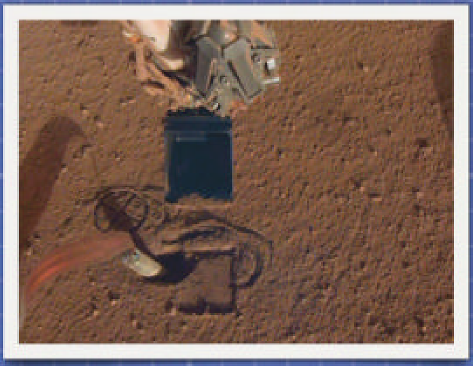
The rest of the HP^3 support instruments had to be removed so that they could gain access to the mole.



Starting the 'pinning' manoeuvre

3 October 2019

The InSight team began using the lander's robotic arm to press the mole up against the soil to increase friction and continue hammering.



InSight's mole shows slight progress

17 October 2019

The pinning manoeuvre gained modest success, as the mole managed to dig nearly two centimetres (0.75 inches) in just over a week.

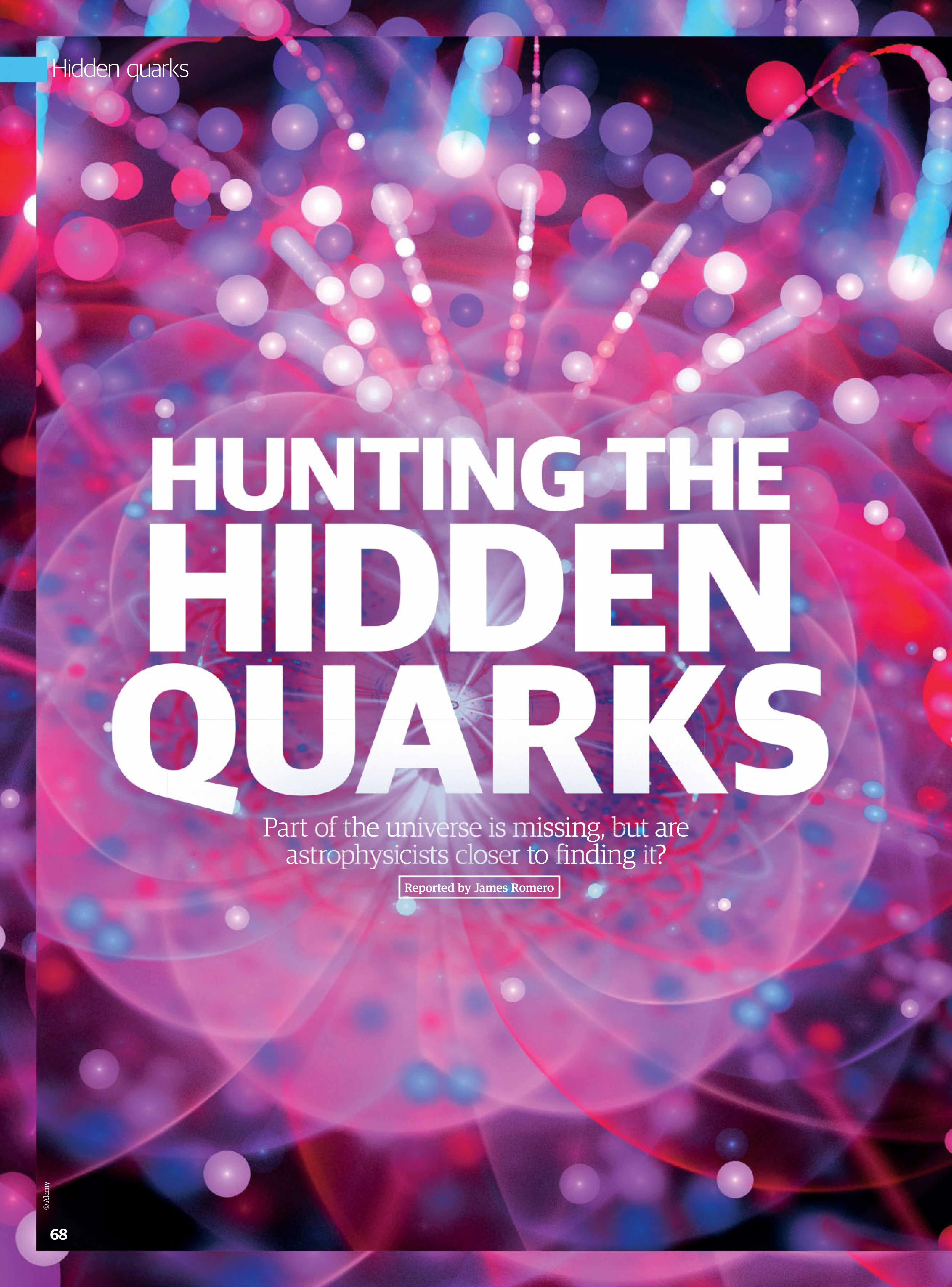
Main objectives

Decipher Mars' interior and formation

InSight will try to understand the inner workings of Mars, determining if there is a rocky or molten core as well as defining the structure of its mantle and crust. By understanding the interior of the Red Planet, scientists hope to apply the knowledge to the Solar System's other planets and how they all formed.

Checking seismic activity

InSight will keep an ear to the ground to carefully monitor the planet's seismic activity. This will determine how frequent and intense any vibrations are. This can also relate to meteorites impacting on the surface to figure out the frequency of those impacts.



HUNTING THE HIDDEN QUARKS

Part of the universe is missing, but are astrophysicists closer to finding it?

Reported by James Romero

© Alamy

"These objects now form the basis for our physical understanding of the universe," read the California Institute of Technology press notice issued in May 2019. It was released to mark the passing of the man who had given the world the fundamental building blocks of nature. Murray Gell-Mann named his discovery the 'quark', though discovery is probably the wrong word. The quark was only proposed back in 1964 to provide a tidy solution to a messy situation particle physics had found itself in.

At this time many new particles of different sizes and charges were being discovered in various small accelerators around the world. There was little sense of how many more scientists might find, and how the members of this growing family related to each other. Gell-Mann, along with George Zweig, provided a pleasing answer. Their independently derived theory challenged the proton and neutron's fundamental building-block status inside the atom. Instead they showed how they, and many other particles, were actually different combinations of the same underlying particle.

In the half a century that has passed since, theoretical physicists have elaborated on this initial proposal, giving the quark a host of properties and characteristics. In modern physics textbooks quarks are governed by quantum chromodynamics (QCD), a quantum field theory which describes the 'strong interaction' between them as force mediated by force-carrier particles called gluons.

We know quarks come in six different types, or flavours, named up, down, strange, charm, bottom and top. They also have a property called spin that gives them a form of angular momentum, like a quantum spinning top, and a charge, described as a variety of colours. And like all particles or quantum entities they behave as waves as well as particles. However, despite all this progress, for experimental physicists the quark remains a more elusive customer. Hiding among its own, scientists have been unable to separate one and investigate it in isolation.

The 50-year story of the quark has allowed us to understand what makes up the stuff of the cosmos, describe and predict new particles and journey back to the origin of all matter, just after the Big Bang. It's also a story which may enter a new chapter following recent theories that individual quarks could finally be found out there in the cosmos, or even produced here on Earth, giving experimentalists their own moment of discovery.

Despite a lack of direct observation, the first supporting evidence for the quark came only a few years after Gell-Mann's original proposal. Experiments at the Stanford Linear Accelerator Center in the late-1960s fired electrons at protons and observed they were bouncing off at weird angles. It suggested they were being deflected by something inside. This support for quark theory didn't explain why certain combinations of quarks produced particles, but others didn't. For example, while three quarks formed baryons like protons and neutrons, and pairs of quarks formed particles called mesons, individual quarks were not allowed.

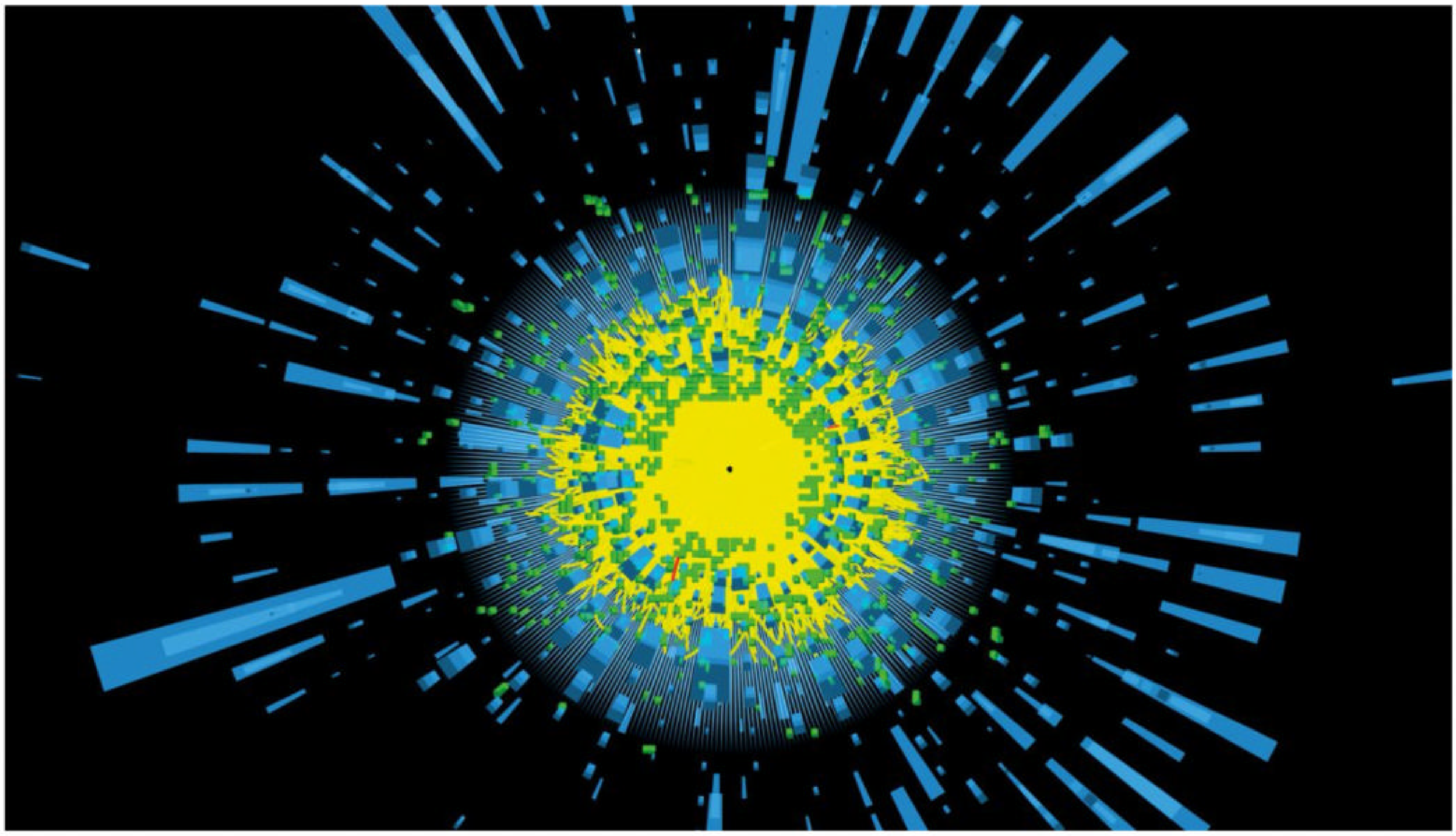
This aversion to singledom was explained by the theory of confinement, which suggested that in order to achieve so-called confinement between two quarks within a hadron - any particle made up of quarks - ever-increasing amounts of energy are required. Eventually this energy becomes so great

© Alamy

Above: Gell-Mann's quark showed that protons, neutrons and other particles were actually combinations of the same underlying particle

Below: One of the first-ever xenon-xenon collision events was recorded by CERN's CMS experiment in 2017

"We know quarks come in six types, or flavours, named up, down, strange, charm, bottom and top"



© CERN

What is a quark?

They make up all matter

Quarks are elementary particles that form the components of the atomic nucleus' protons and neutrons. They are therefore building blocks of all ordinary matter in the universe.

They are ruled by gluons

Quarks are governed by quantum chromodynamics (QCD), a theory that describes the 'strong interaction' between individual quarks through a force-carrier particle called the gluon.

They come in different flavours

We know quarks come in six different types, or flavours: up, down, strange, charm, bottom and top.

They behave like a quantum spinning top

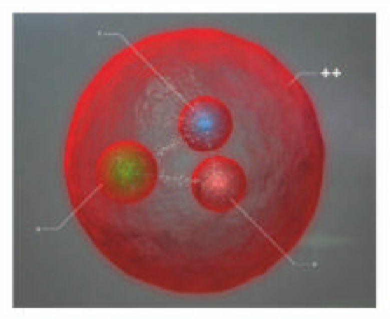
Quarks have another property called spin that gives them a form of angular momentum, like a quantum spinning top.

They don't like their own company

While combinations of three quarks form hadrons, and pairs form mesons, the theory of confinement makes it seemingly impossible for quarks to appear on their own.

Except for the largest

The top quark was the most massive elementary particle when discovered in 1995 at Fermilab. Its size means it decays before it can form a hadron particle, thus providing fleeting evidence of an isolated quark.



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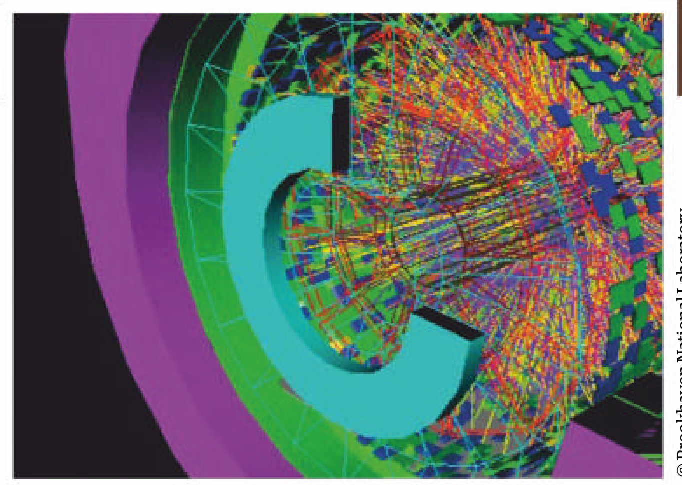

© Brookhaven National Laboratory

Above: Could the signals from neutron stars contain evidence of deconfined quarks sitting on exotic domain walls inside?

Right: A computer rendering of quark-gluon plasma producing collisions between beams of gold ions at the Relativistic Heavy Ion Collider

that it spontaneously produces a quark-antiquark pair, turning the initial hadron into a pair of hadrons instead of producing an isolated quark. Because of this property, some took issue with the quark's label as a fundamental building block of matter. "If it's always inside something else, should we really think about it as an elementary particle?" jokes Zohar Komargodski of the Weizmann Institute of Science in Israel, quoting the naysayers.

If isolation isn't possible, what about direct measurement of the individual contribution of a quark to the properties of the particles they make up? Here again there were challenges. Protons are made up of three quarks: two up and one down. As a result the proton's charge of plus one adds up nicely, with two up quarks contributing plus two-thirds each, and one down contributing minus one-third. However, using angular momentum mathematics to explain the proton's spin of a half proved more difficult. In fact, experiments in the 1980s that smashed high-energy particles into the proton showed the three quarks contributed only around 30 per cent to the proton's spin.

A clue to the answer may come from an oversimplification in the statement 'the proton is made out of three quarks'. In fact, there is a probability for more quarks inside the proton, not to mention the potential contribution of the gluons.

> "We don't measure quarks, we make inferences, and sometimes the calculations are off" **Nobuo Sato**

"Inside the proton is a soup that potentially has many other particles," says Komargodski, who is not particularly worried by this spin discrepancy, often referred to as a 'crisis'. "The proton spin crisis is not a real thing. It's just an experimental question. The theory is well understood and everything works."

While Komargodski is happy to move on, confinement theory holds true, keeping our elementary building blocks bundled up inside baryon and meson cloaks. As a result, advances in our understanding of physics on this scale is left reliant on indirect measure and theoretical mathematics, akin to the study of black holes. "We don't measure quarks, we make inferences, and sometimes the calculations are off, but then we figure out how to correct those mistakes," says Nobuo Sato, a nuclear theorist at the Jefferson Lab National Accelerator Facility in the US.

Though quark deconfinement remains elusive, we do have indirect evidence of one particular quark existing fleetingly in isolation. The top quark was the most massive of all elementary particles when it was discovered in 1995 at Fermilab. Its size means it decays too quickly to form a hadron particle, so the top quark isn't really a fundamental building block of matter. However, evidence of its

The history of the universe in particles

As the cosmos cooled after the Big Bang, elementary particles began to form and combine into the stuff of space-time

Everything stuffed in a football

13.8 billion years ago our entire universe was concentrated into a volume of space about the size of football.

The quark-gluon plasma…

Immediately after inflation the expanded universe cooled, becoming a uniform sea of newly formed fundamental particles like quarks, electrons and their antiparticles.

…with a few extra ingredients

Alongside these components of the atom, the so-called 'Quark Epoch' was also filled with neutrinos, photons of light, dark matter particles and Higgs bosons.

Release of the neutrino

In the first second of the universe, neutrinos were coupled with photons, but these two types of particle decoupled again later.

Matter wins out

At this time there was slightly more matter than antimatter. Particle-antiparticle collisions eventually annihilated the antimatter and the universe was left dominated by matter.

Quarks unite

The first stage of atom building is completed a few millionths of a second after the formation of the first quarks when the cooling universe allows quarks to bond in threes, forming protons and neutrons.

Atoms assemble

About 380,000 years after the Big Bang, the universe had expanded and cooled from billions of Kelvin to 3,000 Kelvin, and protons and electrons combined to form hydrogen atoms.

A helping hand from dark matter

Dark matter particles created more dense regions and the ordinary matter of atomic hydrogen started to fall towards them. Eventually the densest regions created the first stars.

The heavy stuff

The first stars of hydrogen and a bit of helium were short lived, soon exploding in supernovae that created and spread heavier elements and promoted new stellar formation.

Stars become galaxies

A few hundred million years after the Big Bang, the distribution of matter in the universe had produced very dense knots where star formation was high enough to form the first galaxies.

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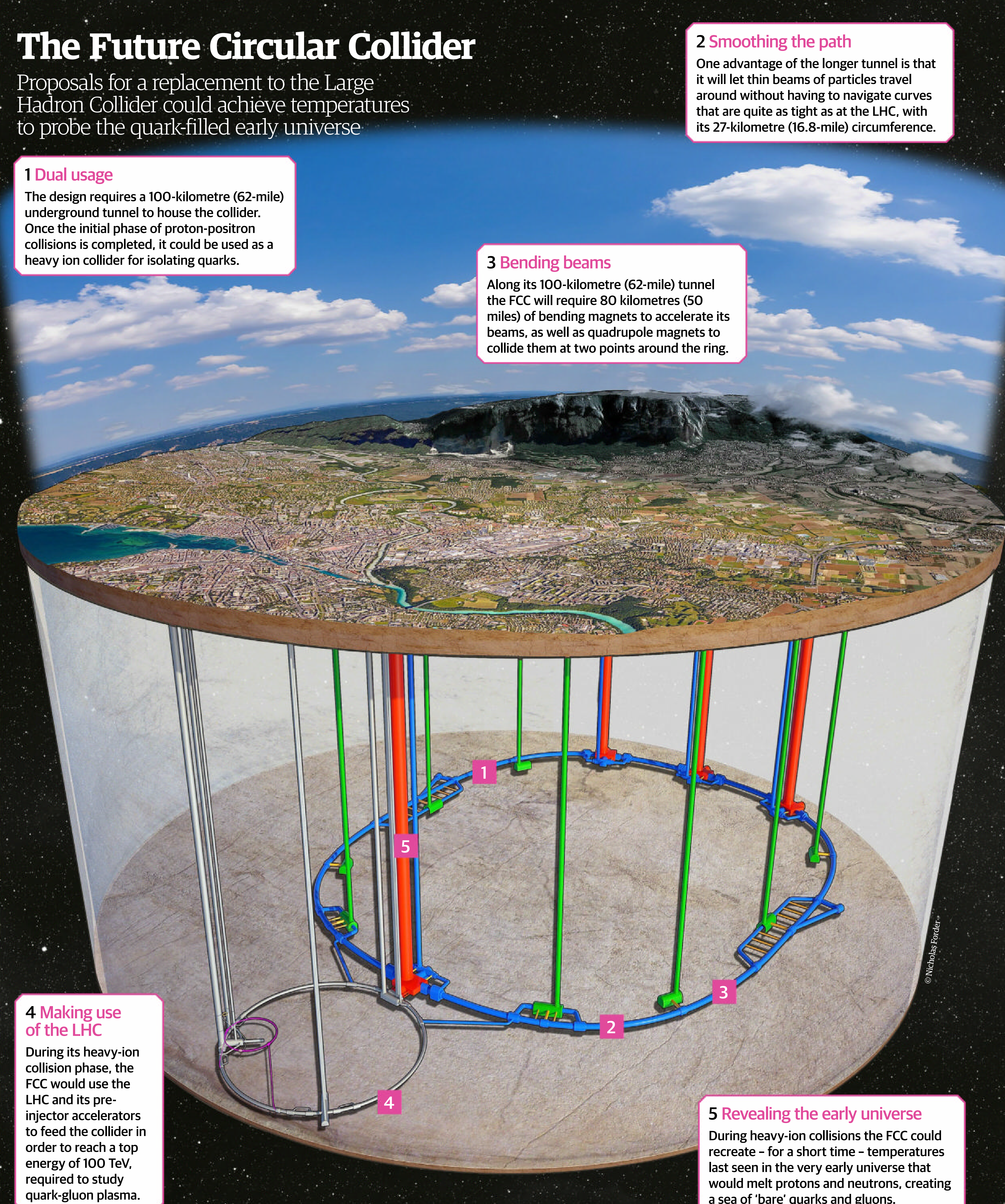
The Future Circular Collider

Proposals for a replacement to the Large Hadron Collider could achieve temperatures to probe the quark-filled early universe



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1 Dual usage

The design requires a 100-kilometre (62-mile) underground tunnel to house the collider. Once the initial phase of proton-positron collisions is completed, it could be used as a heavy ion collider for isolating quarks.

2 Smoothing the path

One advantage of the longer tunnel is that it will let thin beams of particles travel around without having to navigate curves that are quite as tight as at the LHC, with its 27-kilometre (16.8-mile) circumference.

3 Bending beams

Along its 100-kilometre (62-mile) tunnel the FCC will require 80 kilometres (50 miles) of bending magnets to accelerate its beams, as well as quadrupole magnets to collide them at two points around the ring.

4 Making use of the LHC

During its heavy-ion collision phase, the FCC would use the LHC and its pre-injector accelerators to feed the collider in order to reach a top energy of 100 TeV, required to study quark-gluon plasma.

5 Revealing the early universe

During heavy-ion collisions the FCC could recreate – for a short time – temperatures last seen in the very early universe that would melt protons and neutrons, creating a sea of 'bare' quarks and gluons.

fleeting existence as an elementary singleton can be observed. "We can't literally see a top quark, just the aftermath of its decay," says Tara Shears of the University of Liverpool. "But if we can trace and identify the particles it has decayed to, we can reconstruct that top quark and study its behaviour."

While the top quark is unable to form hadrons, what we can learn about it from indirect observation, combined with our exploration of its more compatible cousins through QCD modelling, is providing useful. Lattice QCD is a theoretical framework which uses a four-dimensional grid of points to represent the three dimensions of space and one of time. Based on our broader understanding of quarks, it has proven enormously successful in predicting the masses of many hadrons. "The fact that lattice QCD can provide a simulation whereby, just starting from quarks and gluons, you can describe all the spectrum of hadrons, that's a success," says Sato.

As these QCD models continue to deliver experimentally testable predictions, the appetite for the deconfined hadron quark could have waned. However, in the 2000s interest in another object from QCD, called a domain wall, put it back on the agenda. Domain walls are not three-dimensional particles, but two-dimensional surfaces. And, critically, they only cost a finite amount of energy to create.

QCD mathematics suggests that if you place your proton or neutron on a domain wall, its constituent quarks deconfine. Even more interestingly, physicists like Shigehiro Yasui at Keio University in Tokyo are discussing whether they might exist in nature, inside neutron stars. Could the signals astronomers regularly receive from neutron stars contain evidence of deconfined quarks sitting on exotic domain walls inside? "It's hard to say. It's something that people are thinking about," says Komargodski.

In the meantime, another possibility for deconfining quarks has arisen. In 2011 Nu Xu of the Lawrence Berkeley National Laboratory showed hadrons melt at temperatures around 2 trillion degrees. The result is a soup of deconfined elementary particles called a quark-gluon plasma. One way to achieve such temperatures is to go back in time. The universe in the microseconds after the Big Bang was an intensely hot, energetic liquid of fundamental particles. As it cooled, hadrons and then atoms began to form.

While astronomers cannot peer back this far, there is another less exotic place where scientists can explore this early fleeting phase of matter. In Long Island, New York, the Relativistic Heavy Ion Collider (RHIC) is smashing together large ions, like gold, at near light speed, generating temperatures 250,000-times hotter than within the Sun's core.

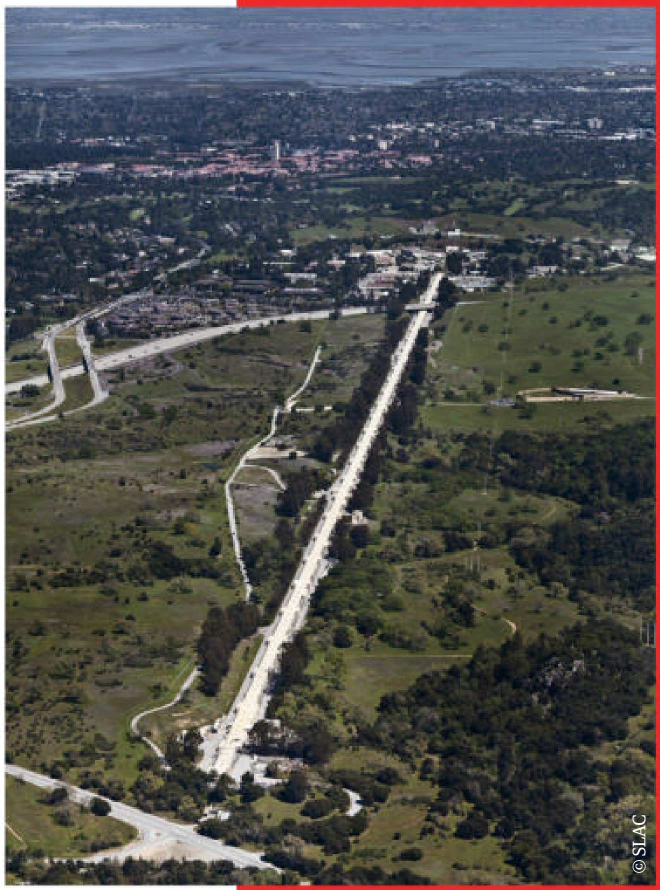
As we await attempts to reach such temperatures here on Earth, the case for a universe of matter built on QCD-described quarks is strong, even if we're unable to isolate the protagonists. However, anyone arguing for quarks' place on the bottom rung of the elementary particle ladder will have challengers from proponents of another famous theory.

In string theory, everything has internal structure because everything is made out of strings. And while there is no evidence for internal quark structure as yet, Komargodski doesn't rule anything out, especially with proposals for the Future Circular Collider (FCC) providing a powerful subatomic microscope to replace the Large Hadron Collider (LHC). "It's like in the 1940s. People did not know that the proton had any internal structure because their microscopes were not strong enough."

While some are seeking answers to fundamental questions inside the quark, many more mysteries remain at the larger scale of individual quark interactions. Sato's team is looking at how quarks and gluons create the emergent phenomenon we measure in protons and neutrons. "The validity of QCD is backed up by its predictive power. However, that doesn't mean that we actually understand how these strong interactions create what we are ultimately made of," he says.

But even these larger scale questions present epic technological challenges. If you were trying to scale up an experiment so individual quarks and gluons are the size of the Earth, the smallest scale detector we can build would need to be located outside the Milky Way. "Imagine someone outside the galaxy trying to measure the light from Earth and figuring out what's going on. This is more or less what we want to do inside the nucleus in terms of quarks and gluons," says Sato.

For half a century the science of quarks has emerged, evolved and matured. Now it is beginning to offer answers to the origin and fundamental make-up of everything in the universe, and all without us having directly observed a solitary building block. "To me, the simplest and most unifying feature is not seeing and studying a single quark. It is understanding the underlying law of nature that gives rise to this behaviour. And that's really satisfying," says Shears. "It doesn't matter that I don't have an up quark signal in my experiment - that's not the way the world works."


© SLAC

Above: The SLAC National Accelerator Laboratory in Stanford has played a fundamental role in the discovery of quarks

Below: The RHIC collider aims to recreate conditions in the universe moments after the Big Bang

How we might isolate the quark

Our hopes of isolating a quark are dependent on particle accelerators like the Relativistic Heavy Ion Collider, smashing together large ions at near light speed. Alternatively we could search for them in nature within the cosmic microwave background formed in the early universe, or in the centre of modern neutron stars.

© Brookhaven National Laboratory

ASK Space

Our experts answer your questions

The Southern Cross is the best way to locate the south celestial pole

© ESO

Did you know?

Since other planets' axes differ, they don't have the same pole stars as us. For example, Mars' north celestial pole is located using Sadr and Deneb of the Northern Cross.

ASTRONOMY

If Polaris is the North Star, is there a 'south star'?

In the Northern Hemisphere, astronomers are very fortunate to have a star, Polaris, very close to the north celestial pole. Polaris will appear to stay fixed in position while the constellations seem to rotate around it due to the Earth's spin about its axis. It is a sensible assumption that there might be a similar guide at the south celestial pole (SCP), the point of sky around which the Southern Hemisphere stars appear to rotate.

However, Polaris is above the celestial pole purely by chance, and there is no useful beacon marking the SCP outright. The closest star, Sigma Octantis in the constellation Octans, is a very dim, fifth-magnitude star which is extremely hard to make out with the naked eye. While Sigma Octantis is the 'south star' to our 'North Star', it does not have the same usefulness as Polaris for astronomers, so often falls by the wayside. To find the SCP, one way is to find the Southern Cross to use 'the pointers' and the star Achernar.

If you would like to see a southern equivalent of Polaris, you will have to wait a very long time. The Earth undergoes a continuous change in the orientation of its rotational axis, known as axial precession. A consequence of precession is the pole star changing due to the change in axial orientation. One cycle of precession is approximately 26,000 years, and in tens of thousands of years Sirius, the 'Dog Star', will be placed close to the south celestial pole. Astronomers certainly won't have a hard time locating such a bright south star!

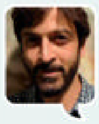
Natasha Lund is an astronomer at the Kielder Observatory, Northumberland

COSMOLOGY

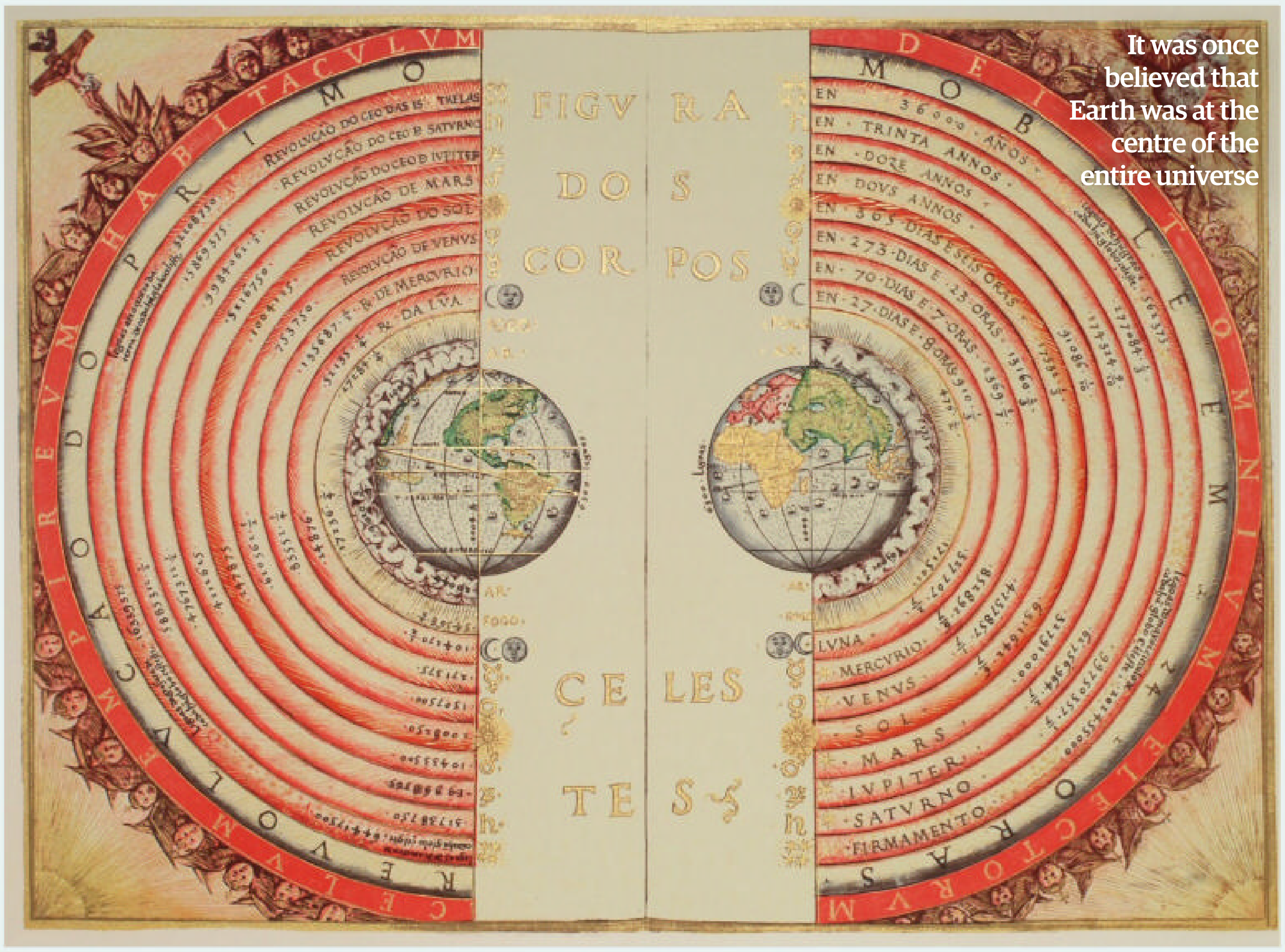
Is there a 'centre' of the universe?

It took until the discovery that the Milky Way itself is but one of many galaxies for cosmologists to formulate what is now known as the cosmological principle: that the universe is statistically homogeneous and isotropic, and therefore has no special central location.

However, astronomical data is good enough that we can now settle this question empirically. The smoothness of the cosmic microwave background and the pattern of anisotropies in it conclusively show that the universe is isotropic - so if there were a special centre, we would have to be situated at it, like at the centre of a bubble. And careful surveys of the number of galaxies around us show that the universe is also homogeneous on large scales, so in fact there is no such bubble.



Dr Seshadri Nadathur is Dennis Sciama Fellow at the Institute of Cosmology and Gravitation at the University of Portsmouth



It was once believed that Earth was at the centre of the entire universe

The Milky Way is part of a larger band of galaxies gravitationally bound together

"Everything in the universe seems to be spinning while in orbit around something"

ASTROPHYSICS

Does the Milky Way orbit anything?

Yes, the Milky Way does orbit something, and it also spins as it does so. Everything in the universe seems to be spinning while in orbit around something. The Moon spins as it goes around Earth; the Earth spins as it goes around the Sun; the Sun spins as it goes around the Galactic Centre 25,000 light years away.

In fact, the entire Milky Way spins as it moves in orbit around our neighbour, Andromeda, which in turn is also spinning. Around the Milky Way are two dwarf galaxies, the Large and Small Magellanic Clouds, and they will both eventually collide with us. A billion years later, Andromeda will collide with us to make a giant future galaxy.

Interestingly, the orbital motions do not stop there. Our group of galaxies, called the Local Group, is falling towards the Virgo Cluster of galaxies some 40 million light years away. Us and Virgo are also moving towards the Great Attractor. In the universe, nothing ever stands still.

Things collapse under gravity, and like an ice skater on a rink pulling their arms in to spin faster, they may spin slowly to start with, but speed up as the collapsing objects become more compact.

Joss Bland-Hawthorn is an Australian Research Council Laureate Fellow professor of physics and director of the Sydney Institute for Astronomy

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ASK Space

Our experts answer your questions

Without further delays, WFIRST will be launched in 2025

©NASA

SPACE EXPLORATION

What is unique about WFIRST?

NASA's Wide Field Infrared Survey Telescope (WFIRST) is an ambitious astronomical observatory set to launch into space in 2025 with a 2.4-metre (7.9-foot) primary mirror – the same size as that of Hubble.

The primary science instrument on WFIRST is the Wide Field Instrument (WFI), a 288-megapixel camera with state-of-the-art infrared detectors – Hubble's infrared camera only has one megapixel. Thus WFIRST can perform surveys for dark energy and exoplanets and infrared astrophysics at hundreds of times the speed of Hubble.

The second instrument on WFIRST is the Coronagraph Instrument (CGI), meant to demonstrate a number of new technologies together in space for the first time. This ambitious technology demonstration is aimed at the direct detection and observation of exoplanets.

A coronagraph blocks out starlight to observe planet light, and existing coronagraphs can image planets a million times fainter than their stars. WFIRST's CGI is being designed to image planets a billion times fainter than their star, a 1,000-fold increase. CGI is considered a stepping stone towards even more powerful coronagraphs on future missions, with the eventual goal being to look for signs of life on Earth-like planets.

Dr Jason Rhodes is project scientist for the WFIRST mission

Venus has an incredibly thick atmosphere

©Tobias Roetsch

SOLAR SYSTEM

How has Venus' atmosphere not been stripped away?

Some of Venus' atmosphere has been stripped away by the solar wind, especially hydrogen and oxygen. The solar wind is a continuous stream of charged particles thrown out by the Sun. When an ion in a planet's atmosphere gets caught by the solar wind, the ion is swept along with the wind.

Venus has no magnetic field, so the solar wind always hits its atmosphere and drags ions away. On Venus most of the atmosphere gas molecules don't ionise easily, and so stay put. The most easily ionised molecule is water. When water molecules high in Venus' atmosphere are hit by the Sun's ultraviolet light, or ions from the solar wind, they break apart and their atoms become ions of hydrogen and oxygen. Those ions are swept away in the solar wind, so its main effect is to rob Venus of its water. There is evidence that Venus lost lots of water early in its history.

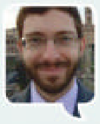
Dr Allan Treiman is the senior staff scientist at the Lunar and Planetary Institute, managed by the Universities Space Research Association

ASTROPHYSICS

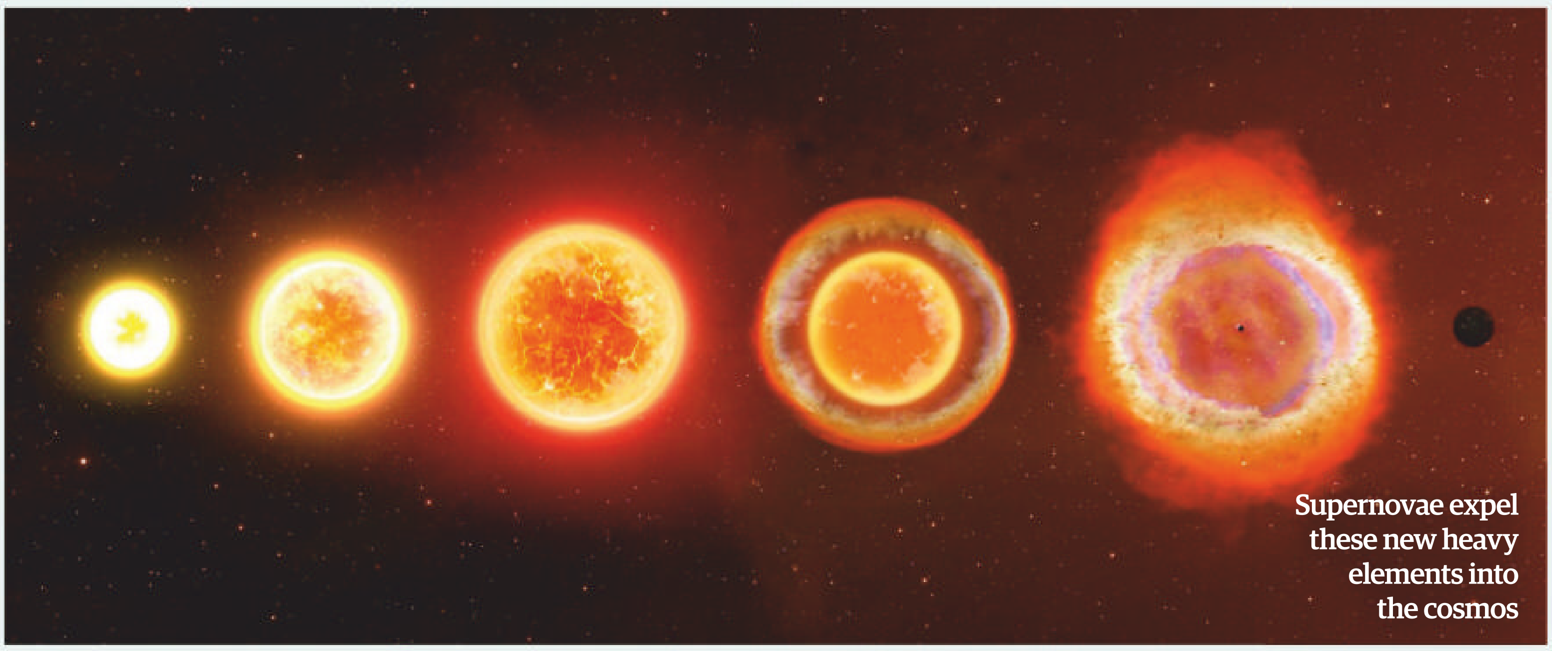
How do stars create elements heavier than iron?

Most of the elements heavier than iron are produced by stars through two types of reactions: the s- and r-processes. In both processes the nucleus of a seed element absorbs a neutron from the surrounding gas. In the s-process – s meaning slow – the neutron has enough time to transform into a proton via beta decay, releasing an electron and a neutrino. The new nucleus now has an extra proton, turning it into the nucleus of a heavier element. In the r-process – r meaning rapid – a second neutron – or more – is absorbed before the first one has had enough time to beta decay.

If the original nuclei are embedded in a neutron-rich environment, they will rapidly absorb large numbers of neutrons and create a range of heavier isotopes of the same element. Most of the new elements created via these two processes will be radioactively unstable and, over time, will radioactively decay into lighter elements. Those will decay in turn until stable isotopes are finally reached.



Dr Or Graur is an NSF astronomy and astrophysics postdoctoral fellow at the Harvard-Smithsonian Center of Astrophysics



Supernovae expel these new heavy elements into the cosmos

©Tobias Roetsch

ASTROPHYSICS

How does a black hole devour a star?

When a star passes too close to a supermassive black hole, the gravitational forces on the star are so strong it gets torn apart. This effect is similar to how gravity from the Moon causes oceans to bulge on Earth, creating tides. The difference in the pull from the black hole on the side of the star facing it and the pull on the opposite side is so strong that the star gets stretched to the point where it is ripped apart into a thin stream of gas. Because these 'tidal forces' are responsible for shredding the star, we call this process a 'tidal-disruption event'.

Much of the gas gets flung away at high speeds, but some of it remains gravitationally bound to the black hole and keeps looping around it over and over. As this happens the stream of stellar gas crashes into itself repeatedly and more of it gets blown away, while a small fraction gets funnelled towards the black hole and is slowly consumed over the next year or so. This whole process is extremely violent and chaotic, and the stellar debris is heated to very high temperatures, which causes it to release huge amounts of energy and glow as bright as 100 billion Suns until it is finally fully consumed.

Dr Thomas Holoien is a Carnegie Fellow at the Carnegie Observatories specialising in tidal disruption events

> "The star gets stretched to the point where it is ripped apart into a thin stream of gas"

Did you know?

The closest black hole to Earth that we know of is V616 Monocerotis, lying approximately 3,000 light years away. The next furthest is Cygnus X-1, 6,000 light years away.

Supermassive black holes reside at the centre of galaxies

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Red light friendly
In order to preserve your night vision, you should read our observing guide under red light

What's in the sky?

Source: Wikipedia Commons © Asim Patel

14 DEC
The Geminids reach their peak of 120 meteors per hour

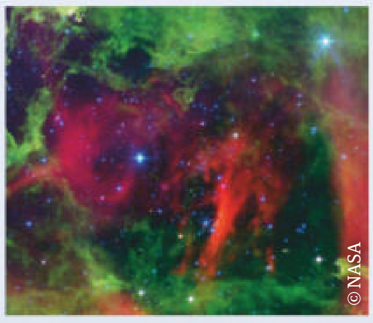
20 DEC
December Leonis Minorids reach their peak of five meteors per hour

23 DEC
The Moon and Mars make a close approach, passing within 3°20' of each other in Libra

26 DEC
TAKE CARE!
Annular solar eclipse visible from Africa, Oceania, Asia, Federated States of Micronesia, Spratly Islands, Wake Island, Paracel Islands and British Indian Ocean Territory

29 DEC
The Moon and Venus make a close approach, passing within 0°58' of each other in Capricornus

29 DEC
The open star cluster NGC 2244 is well placed for observation in Monoceros



© NASA

Jargon buster

Conjunction

A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)

Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

Declination (Dec)

This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Magnitude

An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

Opposition

When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Greatest elongation

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.

15 DEC

The Moon and Beehive Cluster (M44) make a close approach in Cancer

Source: Wikipedia Commons © Miguel Garcia

15 DEC

The open star cluster NGC 1981 is well placed for observation in Orion

22 DEC

December solstice

23 DEC

Conjunction between the Moon and Mars in Libra

Source: Wikipedia Commons © Roberto Mura

Source: Wikipedia Commons © Roberto Mura

28 DEC

Open star cluster NGC 2232 is well placed in Monoceros

29 DEC

Conjunction between the Moon and Venus in Capricornus

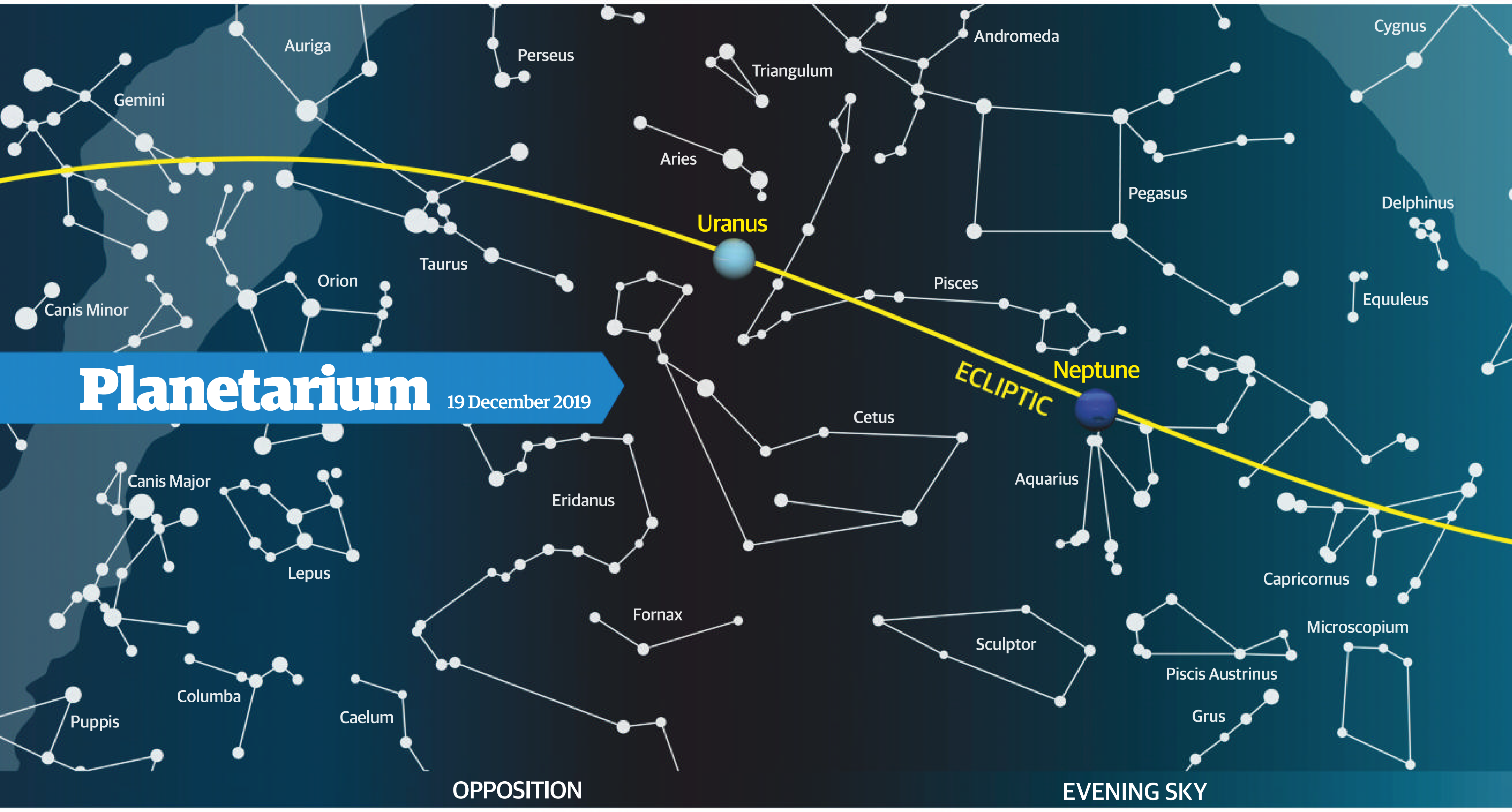
2 JAN

Open star cluster Messier 41 is well placed for observation in Canis Major

Source: Wikipedia Commons © Tomruen

- Naked eye
- Binoculars
- Small telescope
- Medium telescope
- Large telescope

Planetarium 19 December 2019



Moon calendar

* The Moon does not pass the meridian on 12 December

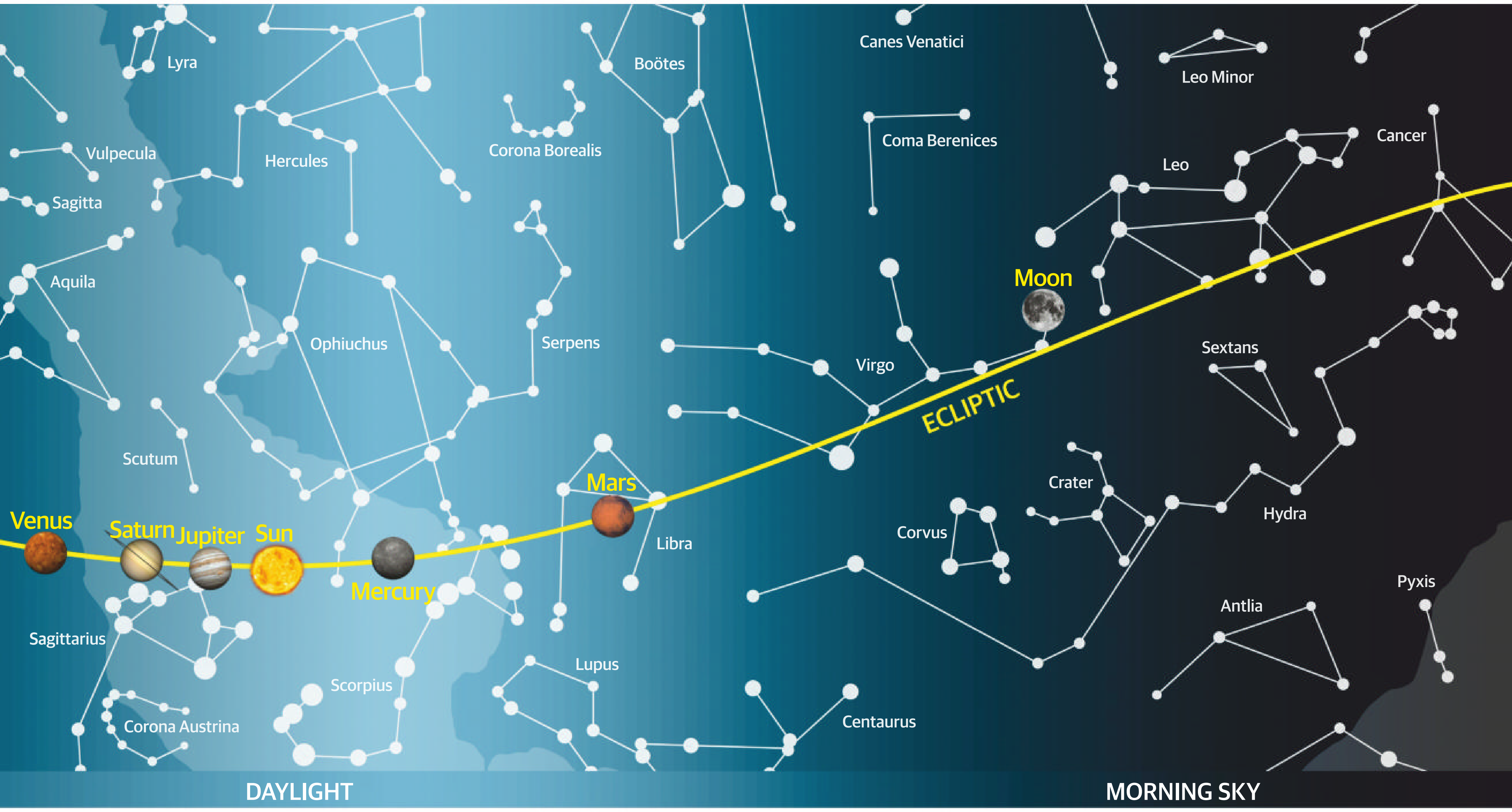
			5 DEC 64.2% ▲13:31 ▼--:--	**6** DEC 73.2% ▼01:00 ▲13:48	**7** DEC 81.4% ▼02:07 ▲14:05	**8** DEC 88.6% ▼03:14 ▲14:22
9 DEC 94.3% ▼04:24 ▲14:42	**10** DEC 98.2% ▼05:35 ▲15:07	**11** DEC 99.9% ▼06:47 ▲15:37	**12** DEC FM --:--%* ▼07:59 ▲16:16	**13** DEC 99.2% ▼09:05 ▲17:06	**14** DEC 96.0% ▼10:03 ▼18:08	**15** DEC 90.3% ▼10:50 ▲19:20
16 DEC 82.3% ▼11:27 ▲20:39	**17** DEC 72.4% ▼11:57 ▲21:59	**18** DEC 61.3% ▼12:21 ▲23:20	**19** DEC LQ 49.5% ▼12:43 ▲--:--	**20** DEC 37.8% ▲00:41 ▼13:03	**21** DEC 26.8% ▲02:01 ▼13:24	**22** DEC 17.1% ▲03:21 ▼13:46
23 DEC 9.3% ▲04:41 ▼14:13	**24** DEC 3.7% ▲05:59 ▼14:45	**25** DEC 0.6% ▲07:12 ▼15:24	**26** DEC NM 0.1% ▲08:18 ▼16:13	**27** DEC 1.9% ▲09:12 ▼17:11	**28** DEC 5.9% ▲09:56 ▼18:15	**29** DEC 11.7% ▲10:29 ▼19:23
30 DEC 18.9% ▲10:56 ▼20:31	**31** DEC 27.2% ▲11:18 ▼21:38	**1** JAN 36.3% ▲11:37 ▼22:45	**2** JAN 45.8% ▲11:53 ▼23:51			

% Illumination
▲ Moonrise time
▼ Moonset time

FM Full Moon
NM New Moon
FQ First quarter
LQ Last quarter

All figures are given for 00h at midnight (local times for London, UK)

What's in the sky?



Illumination percentage

	12 DEC	19 DEC	26 DEC	2 JAN
MERCURY	90%	90%	100%	100%
VENUS	90%	90%	80%	80%
MARS	100%	100%	100%	100%
JUPITER	100%	100%	100%	100%
SATURN	100%	100%	100%	100%

Planet positions

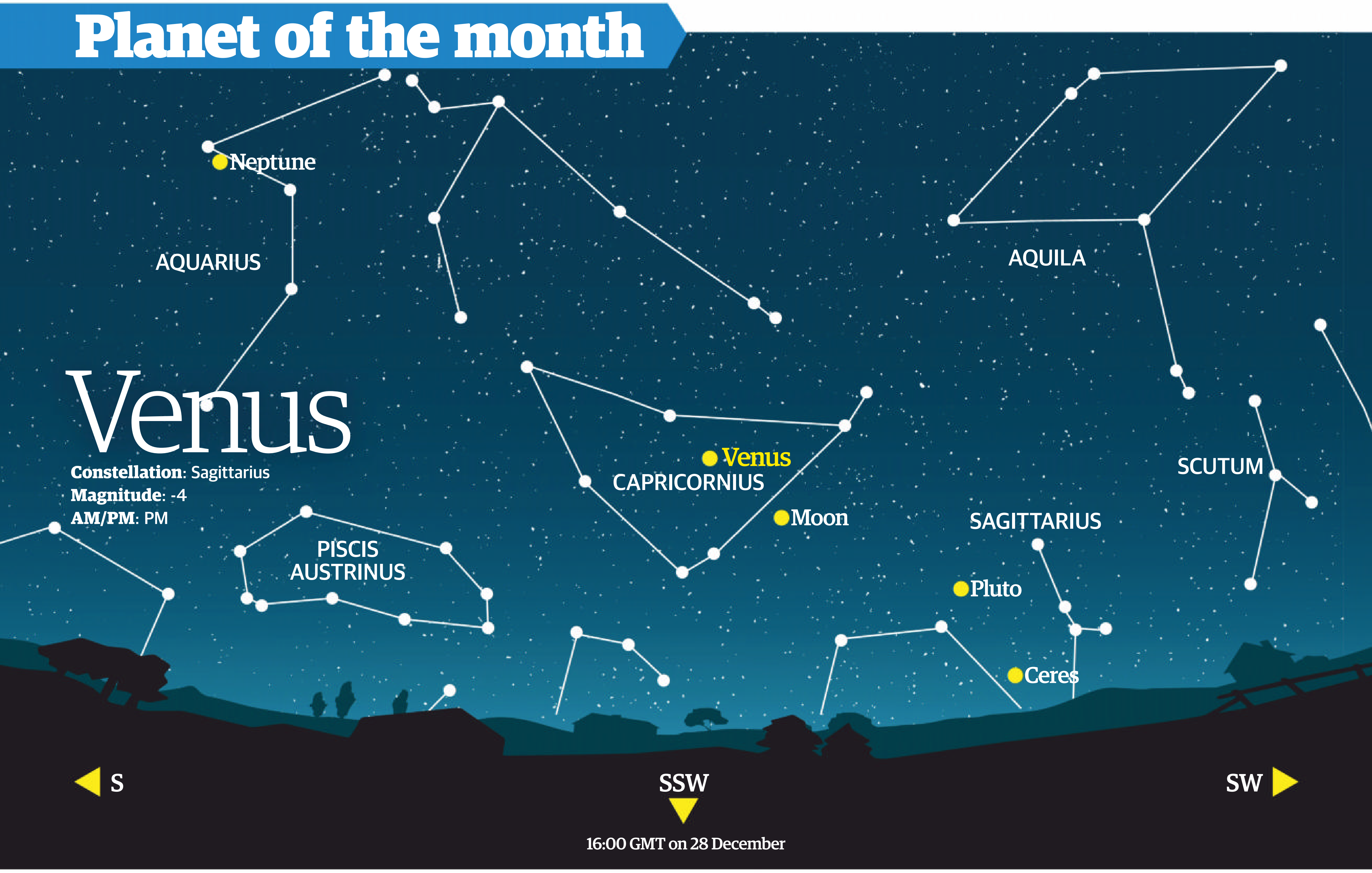
All rise and set times are given in GMT

	Date	RA	Dec	Constellation	Mag	Rise	Set
MERCURY	5 DEC	15h 26m 39s	-16° 55' 20"	Libra	-0.6	05:57	15:05
	12 DEC	16h 06m 46s	-19° 54' 26"	Scorpius	-0.6	06:27	14:59
	19 DEC	16h 50m 41s	-22° 22' 39"	Ophiuchus	-0.6	07:00	15:00
	26 DEC	17h 37m 01s	-24° 01' 26"	Ophiuchus	-0.7	07:30	15:07
	2 JAN	18h 25m 04s	-24° 40' 18"	Sagittarius	-1.0	07:55	15:22
VENUS	5 DEC	18h 47m 49s	-24° 33' 44"	Sagittarius	-3.9	10:07	17:36
	12 DEC	19h 25m 35s	-23° 43' 42"	Sagittarius	-4.0	10:11	17:52
	19 DEC	20h 02m 37s	-22° 19' 05"	Sagittarius	-4.0	10:11	18:11
	26 DEC	20h 38m 40s	-20° 22' 45"	Capricornus	-4.0	10:06	18:32
	2 JAN	21h 13m 35s	-17° 58' 27"	Capricornus	-4.0	09:59	18:55
MARS	5 DEC	14h 31m 29s	-14° 16' 17"	Libra	1.7	04:47	14:25
	12 DEC	14h 49m 46s	-15° 44' 16"	Libra	1.7	04:46	14:08
	19 DEC	15h 08m 21s	-17° 06' 46"	Libra	1.6	04:45	13:51
	26 DEC	15h 27m 18s	-18° 23' 08"	Libra	1.6	04:44	13:34
	2 JAN	15h 46m 34s	-19° 32' 39"	Libra	1.6	04:42	13:19
JUPITER	5 DEC	18h 01m 01s	-23° 18' 16"	Sagittarius	-1.8	09:11	16:58
	12 DEC	18h 07m 53s	-23° 18' 14"	Sagittarius	-1.8	08:51	16:38
	19 DEC	18h 14m 51s	-23° 17' 01"	Sagittarius	-1.8	08:30	16:17
	26 DEC	18h 21m 51s	-23° 14' 36"	Sagittarius	-1.8	08:09	15:57
	2 JAN	16h 41m 10s	-21° 34' 03"	Sagittarius	-1.8	05:49	13:59
SATURN	5 DEC	19h18m 28s	-22° 07' 32"	Sagittarius	0.6	10:21	18:24
	12 DEC	19h 21m 39s	-22° 02' 00"	Sagittarius	0.6	09:56	18:00
	19 DEC	19h 24m 57s	-21° 55' 59"	Sagittarius	0.6	09:31	17:36
	26 DEC	19h 28m 21s	-21° 49' 29"	Sagittarius	0.6	09:06	17:13
	2 JAN	18h 48m 42s	-22° 28' 51"	Sagittarius	0.6	08:02	16:01

This month's planets

Venus, Jupiter and Saturn will form a bright planetary chain across the twilight sky this month

Planet of the month



Venus

Constellation: Sagittarius
Magnitude: -4
AM/PM: PM

16:00 GMT on 28 December

Our 'Planet of the Month' this issue really deserves its title because it will look like a lantern blazing in the western sky over the festive period. Venus will be a gorgeous 'evening star', outshining everything else in the sky apart from the Moon and the Sun. Even after we move into 2020 it will continue to dominate the sky after sunset, appearing the most impressive it has for a long time.

Being closer to the Sun than Earth, Venus is hotter than our world, but its thick, curdled atmosphere of carbon dioxide has inflicted brutal global warming on Venus for many millions of years, so its surface temperature is actually higher than Mercury's, the closet world to the Sun. It rains acid there, its atmosphere is poisonous and its lightning-illuminated clouds are so thick they permanently hide the Sun.

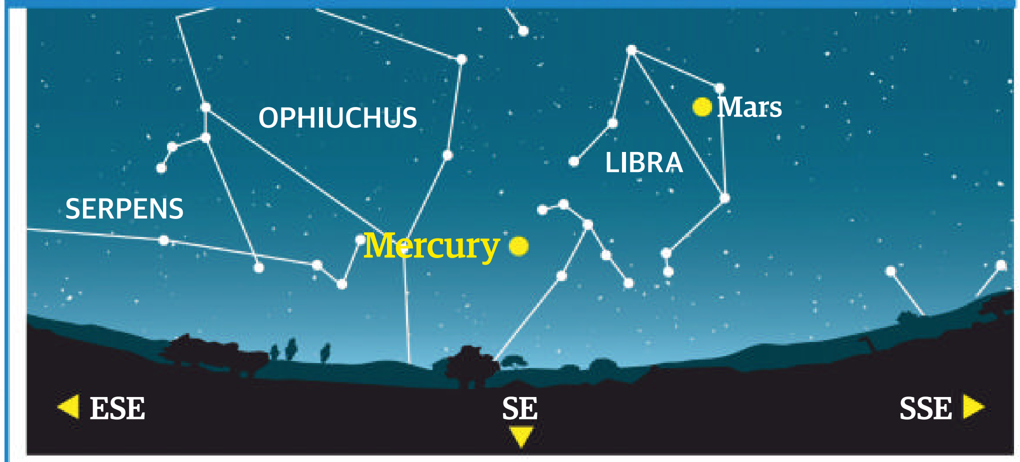
As our observing period begins Venus will be the middle link in a chain of three planets stretched out across the western sky after sunset. To its upper left will be Saturn, fainter and shining with a warmer, more golden hue. To its lower right, embedded in the twilight glow, Jupiter will also be fainter and harder to see. This planetary parade will be an eye-catching sight until the planets begin to drift apart by the middle of the month, with Venus and Saturn drawing closer and closer together until they pass on the evening of 11 December, when they will be less than two degrees - or four Moon widths - apart. After that date Venus will rapidly climb away from Saturn, remaining visible a little longer each night.

On Christmas Eve, as frazzled parents shoo their children to bed with veiled threats of Santa boycotting their house if they don't behave, Venus will be a beautiful sight, blazing among the stars of Capricornus, visible very soon after the Sun has set. On 28 December Venus will be joined in the southwestern sky by a very thin fingernail-clipping crescent Moon. The view will actually be better the night after that, when the Moon will have drifted eastwards to shine to the Venus' upper left and will be illuminated by the subtle rosy-purple glow of Earthshine.

By 2 January Venus will still be a blazingly bright beacon in the western sky as darkness falls, not setting until 19:00. And all through January it will just get more and more beautiful. The camera on your mobile phone will be more than good enough to take lovely images of it shining brightly in the sky, so give it a go.

This month's planets

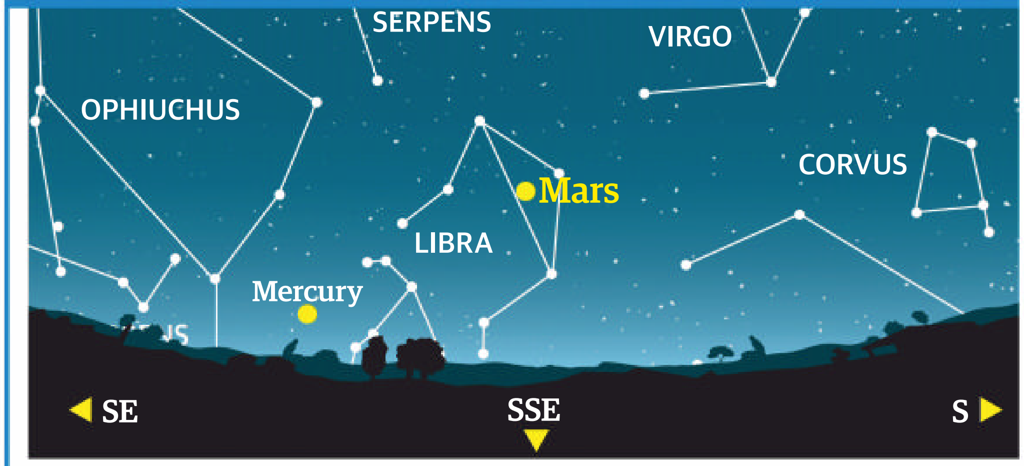
Mercury 07:30 GMT on 15 December



Constellation: Libra
Magnitude: -0.6
AM/PM: AM

Mercury, closest planet to the Sun, will be visible low in the east before sunrise. At magnitude -0.6 it will be an easy naked-eye object. Mercury will already be past its best as December begins, dropping lower in the sky each morning, and by mid-December it will be so close to the Sun it will be very challenging to see.

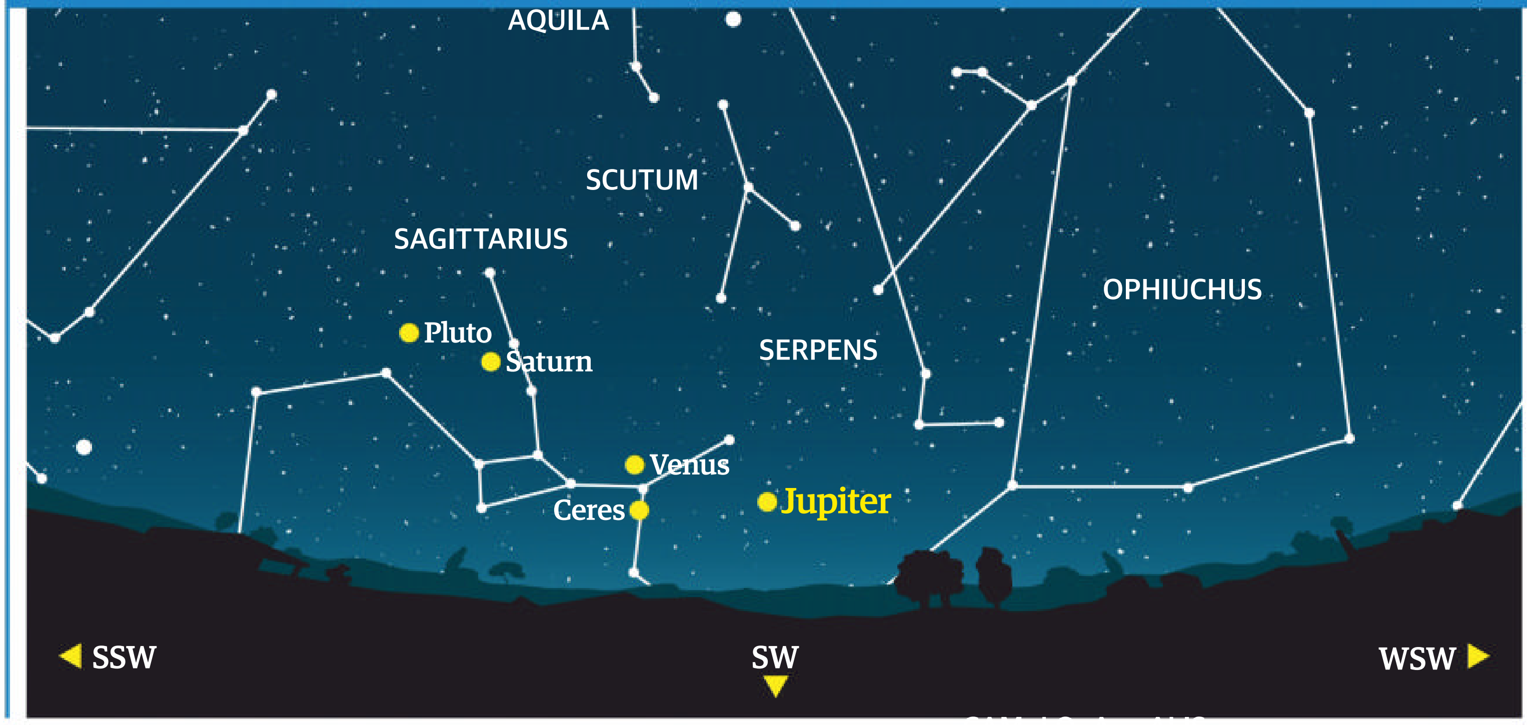
Mars 08:00 GMT on 17 December



Constellation: Libra
Magnitude: 1.8
AM/PM: AM

The Red Planet will be a Polaris-bright 'morning star' hanging low in the east before sunrise, shining to the upper right of brighter Mercury and rising around three hours before the Sun. Mars will have a pair of lovely close encounters with the waning crescent Moon on the mornings of 22 and 23 December.

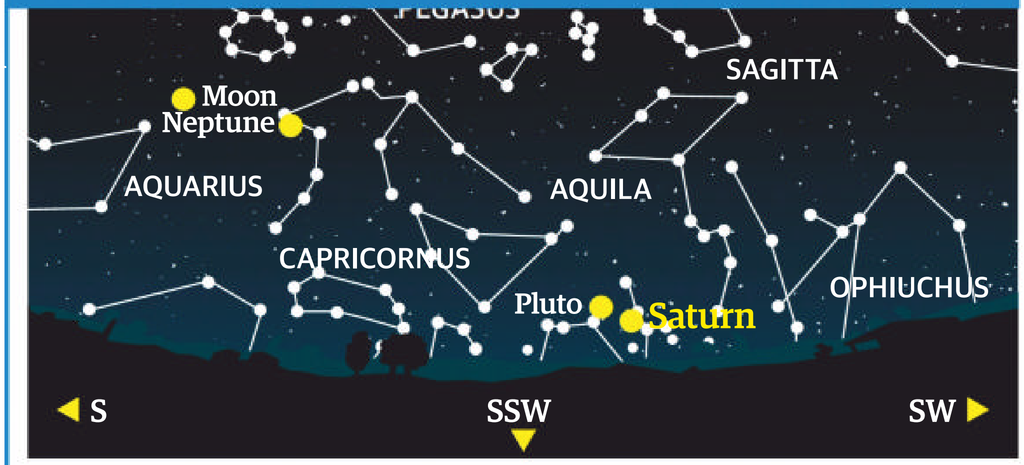
Jupiter 16:30 GMT on 1 December



Constellation: Sagittarius
Magnitude: -1.8
AM/PM: PM

At the start of this month Jupiter will be an 'evening star', visible low in the southwest after sunset. Although its magnitude of -1.8 means it will be visible to the naked eye, it will be overshadowed by much brighter Venus, which will be shining to its upper left, and even by Saturn, which will be shining to Venus' upper left, the three planets forming a chain stretched out across the twilight sky. As December's days pass Jupiter will quickly lose height and fall towards the Sun until it is too close to it to be seen. After mid-December we'll lose sight of it, so make the most of it while you can.

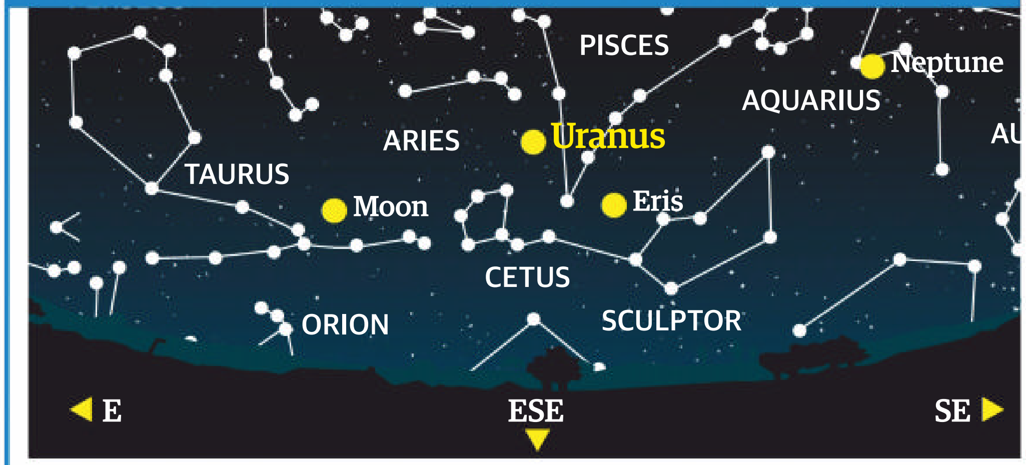
Saturn 17:30 GMT on 05 December



Constellation: Sagittarius
Magnitude: 0.6
AM/PM: PM

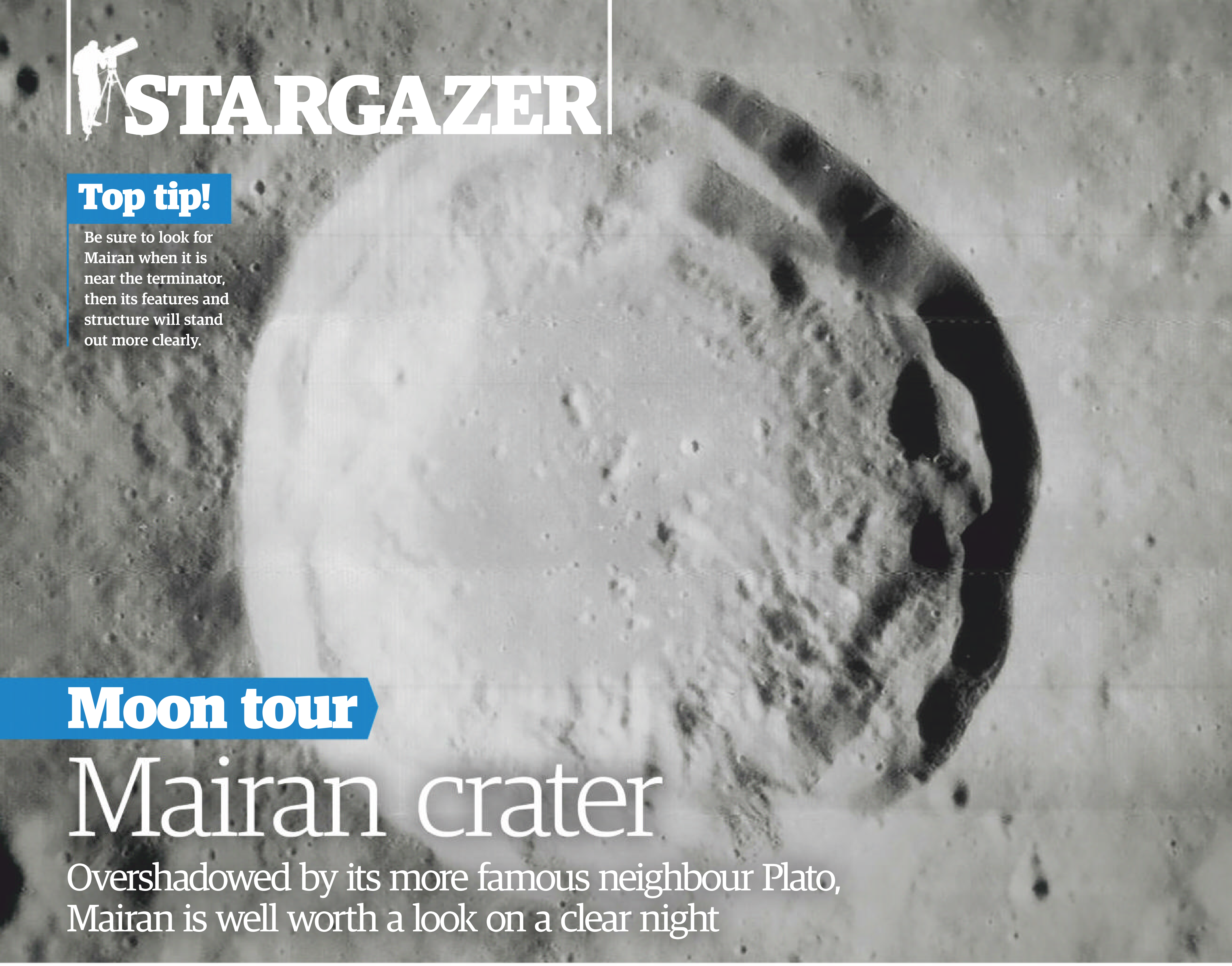
At the start of December you'll find Saturn shining to the upper left of much brighter Venus, which itself will lie to the upper left of Jupiter, the three worlds stretched out across the twilight sky. As the days pass Saturn and Venus will grow closer until they pass on the evening of 11 December and are less than two degrees apart.

Uranus 17:30 GMT on 10 December



Constellation: Aries
Magnitude: 5.7
AM/PM: PM

With a magnitude of 5.7 this month, Uranus is technically a naked-eye planet under dark conditions. Uranus is a tiny greenish-hued 'star' visible in binoculars, already quite high in the east as darkness falls. An almost-full Moon will lie beneath it on the evening of 8 December, which will help you to track it down.



Moon tour

Mairan crater

Overshadowed by its more famous neighbour Plato, Mairan is well worth a look on a clear night

Top tip!

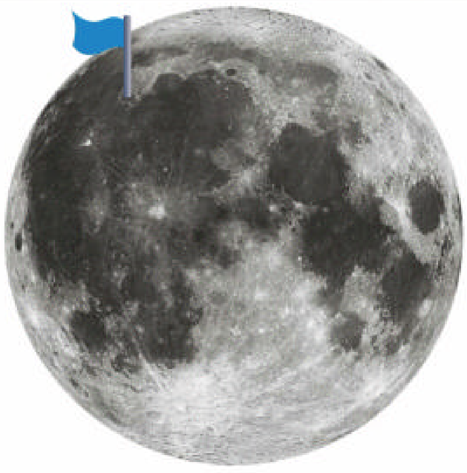
Be sure to look for Mairan when it is near the terminator, then its features and structure will stand out more clearly.

There are a lot of craters on the Moon that would be more famous and better appreciated if they weren't so close to other features that were bigger, more prominent or just better looking. If you scan the lunar landscape around 'celebrity' craters like Copernicus and Ptolmaeus you'll find lots of smaller craters that would be very popular targets for lunar observers if only they weren't so close to those beasts.

Likewise, in the low-lying areas on either side of the curved dinosaur spine of the jagged Appennine Mountains, you'll find lots of smaller craters, hills and rilles worth looking at, but with the Appenines jutting out of the surface so magnificently, nothing in their shadow gets a look in.

The same is true of this month's destination on our on-going Moon Tour. Look up towards the 'top' of the Moon at any phase past first quarter and you will see the dark oval of Plato, a crater with a floor as smooth as marble - or so it appears under low magnifications. To Plato's left - or to its west - you'll see the equally famous semi-circular bay of Sinus Iridum that looks like someone has taken a bite out of the lunar crust up there on the northern shore of Mare Imbrium. Both those features are spectacular sights in a telescope, but if you can tear your eyes away from them and let them drift a little further west you'll find a small crater blasted out of the light-coloured rocky peninsula that leads away from Sinus Iridium, to the south of Sinus Roris. This crater is Mairan.

Physically Mairan is a 39-kilometre (24-mile) wide, four-kilometre (2.5-mile) deep hole, or pit, blasted out of the Moon unknown millennia ago. In common with countless hundreds of thousands of other craters its size, Mairan has steep, terraced walls, which are slumped in places, leading down to a relatively flat floor with a scattering of smaller craters sprayed across it. Mairan has many small secondary impact craters spattered around it, none of them particularly noteworthy.



So, when can you see this crater for yourself? At the start of our observing period Mairan is not visible, as it will be deep in the darkest depths of the lunar night. It won't be until 8 December that the crater begins to return to view, as the terminator - the line between night and day - sweeps over it and the first slanting rays of sunlight fall on its western rim. Between 8 and 11 December the crater will be a very attractive object in telescope eyepieces as its close proximity to the terminator will mean its walls, floor and rim are all illuminated from the side, their shadows making the crater look very prominent. As the Moon reaches full on 12 December, Mairan will fade into the background; with the Sun overhead it will look less like a hole and more like a light circle with a darker floor through telescopes.

On 22 December the terminator will sweep over the crater again, this time from the east, and it will be plunged into darkness once more. We won't be able to see it again until long after the end of our observing period.

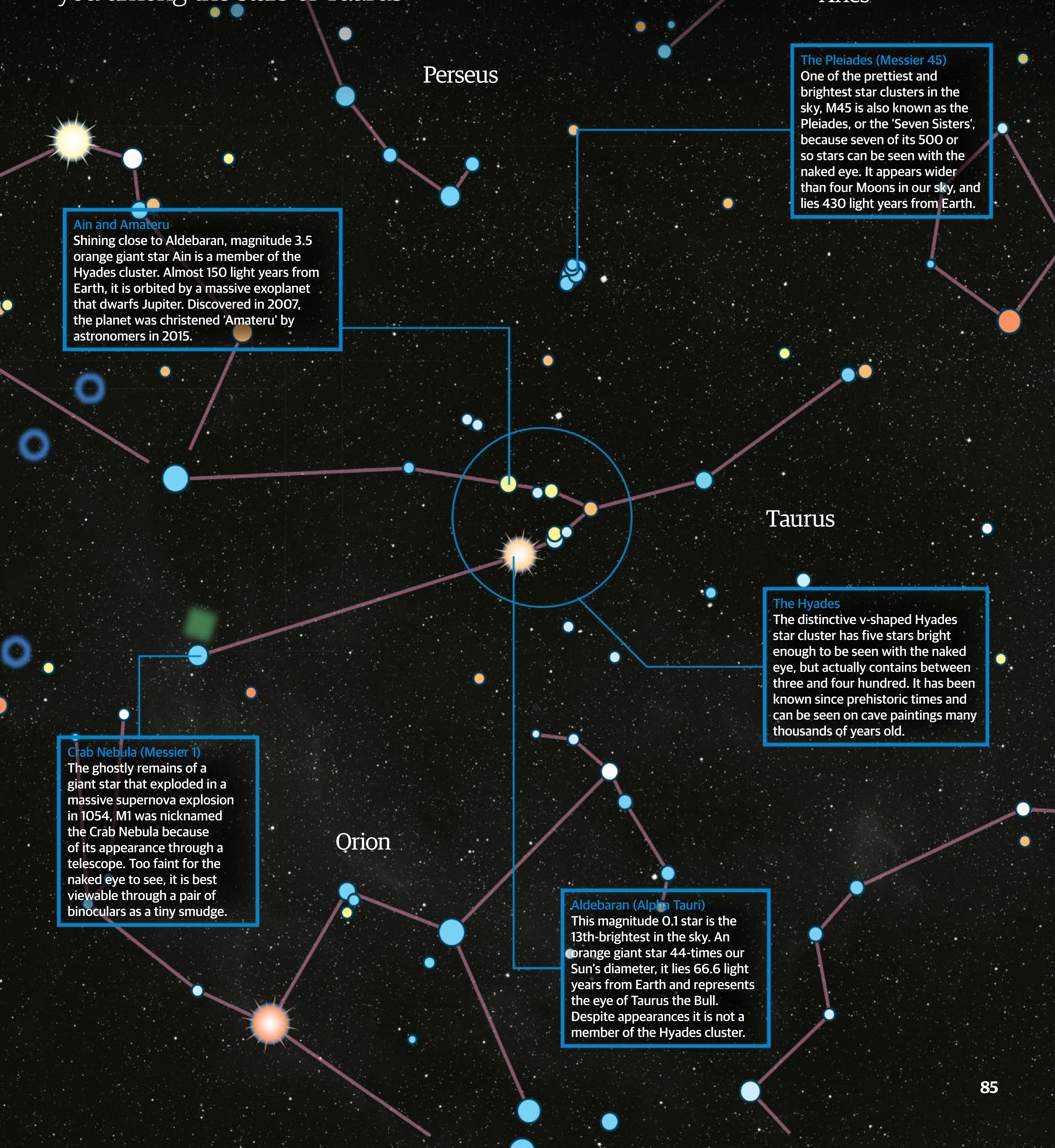
If Mairan was on its own, somewhere further south out on the dark rolling plain of Mare Imbrium, for instance, it would attract a lot more attention. But embedded in that peninsula it is usually overlooked by observers impatient to swing their telescopes towards Plato or Sinus Iridum - but you can't really blame them for that.

However, the crew of Apollo 15 obviously thought the crater was worthy of some attention, because as they flew over it in 1971 they took several photos of it from lunar orbit. More recently NASA's Lunar Reconnaissance Orbiter has taken much higher resolution images of the crater showing details on its inner walls, including boulders and landslides.

© NASA

Naked eye & binocular targets

Brave the cold and find some of the wonders waiting for you among the stars of Taurus



The Pleiades (Messier 45)
One of the prettiest and brightest star clusters in the sky, M45 is also known as the Pleiades, or the 'Seven Sisters', because seven of its 500 or so stars can be seen with the naked eye. It appears wider than four Moons in our sky, and lies 430 light years from Earth.

Ain and Amateru
Shining close to Aldebaran, magnitude 3.5 orange giant star Ain is a member of the Hyades cluster. Almost 150 light years from Earth, it is orbited by a massive exoplanet that dwarfs Jupiter. Discovered in 2007, the planet was christened 'Amateru' by astronomers in 2015.

The Hyades
The distinctive v-shaped Hyades star cluster has five stars bright enough to be seen with the naked eye, but actually contains between three and four hundred. It has been known since prehistoric times and can be seen on cave paintings many thousands of years old.

Crab Nebula (Messier 1)
The ghostly remains of a giant star that exploded in a massive supernova explosion in 1054, M1 was nicknamed the Crab Nebula because of its appearance through a telescope. Too faint for the naked eye to see, it is best viewable through a pair of binoculars as a tiny smudge.

Aldebaran (Alpha Tauri)
This magnitude 0.1 star is the 13th-brightest in the sky. An orange giant star 44-times our Sun's diameter, it lies 66.6 light years from Earth and represents the eye of Taurus the Bull. Despite appearances it is not a member of the Hyades cluster.

The Seagull Nebula (IC 2177)

© ESO

Deep sky challenge

Tour beyond the Orion Nebula

Track down some of winter's lesser-known wonders on the next clear and frosty night

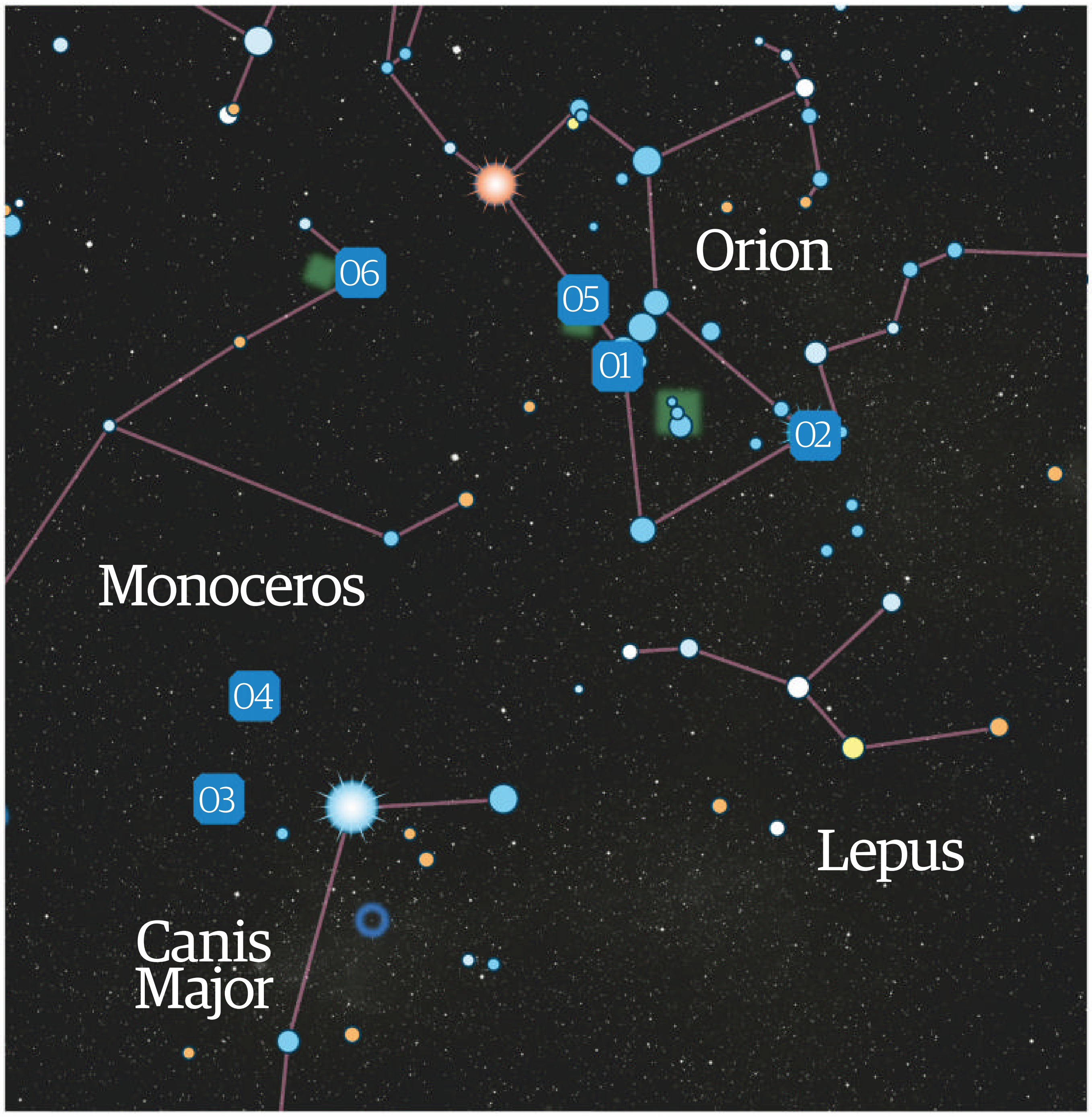
Just as it's easy for them to return to the same 'celestial celebrities' night after night in the summer - the Ring Nebula, M13 and M51 all repeatedly draw the eye away from other things - the deep-sky observer's winter comforts are the bright, swirling clouds of the stunning Orion Nebula and the glittering spectacle of the Pleiades. But there are many other objects in the winter sky just as - if not more - deserving of attention. And given that December nights are often beautifully clear and brutally cold, this is a good time to wrap up warm, head out and track down some of the objects often overlooked in favour of their brighter, brasher neighbours.

For example, while most amateur astronomers have heard of the Horsehead Nebula, very few have ever seen it. This is because although photographs suggest it is a very dramatic-looking object - a bold knight chess piece silhouetted against a cherry-red curtain of light - in all but the largest telescopes it is little more than a dark notch in a slightly lighter area. Likewise, the Rosette Nebula can be seen on every wide-field photo taken of Orion, looking like an orange flower to the left of Betelgeuse, but its low surface brightness and wide area means it is little more than a puff of smoke with a star-spangled centre through most telescopes.

Witch Head Nebula (IC 2118)

©NASA

Deep sky challenge



© Wil Tirion

1 The Horsehead Nebula (Barnard 33)

This dark nebula looks strikingly similar to a horse's head in long exposures, but you'll need a large telescope, a very dark sky, perfect seeing and maybe even a filter if you're going to see it.

2 The Witch Head Nebula (IC 2118)

Illuminated by the icy-blue glare of nearby giant star Rigel, this tenth-magnitude cloud of gas looks like the face of a witch - complete with crooked nose - through large-aperture telescopes.

3 Thor's Helmet (NGC 2359)

Observing this 11th-magnitude nebula is a huge challenge. Under a dark sky a large telescope fitted with a nebula filter will show hints of filaments and mottling within it.

4 The Seagull Nebula (IC 2177)

If you use averted vision looking at this tenth-magnitude nebula through a large telescope's widest field eyepiece, you might see it has a bright 'head' and faint, outstretched 'wings'.

5 Messier 78

Although a small telescope will easily show this nebula's bright centre, larger instruments and high magnifications are needed to see subtle detail on its edges.

6 The Rosette Nebula (NGC 2237)

The Rosette Nebula is bright and colourful in photos, but visually it appears as a vague, grey-white smudge through large-aperture telescopes on Moon-free nights.

The Horsehead Nebula (Barnard 33)

© Wiki/Stephanh

The Northern Hemisphere

The December constellations swing into view, offering an impressive array of targets to enjoy

If you're a fan of splitting double stars with your telescope then head over to the constellation of Aries (the Ram), which makes its appearance this month, bounded by the star patterns of Taurus (the Bull), Pisces (the Fishes) and Cetus (the Whale). In particular, binary star systems Lambda Arietis, Epsilon Arietis and Mesarthim are splendid targets to resolve for astronomers with medium- to large-sized telescopes. Meanwhile, orange giants Hamal (the Head of the Ram) and Botein (Little Belly) can be picked out using nothing more than the naked eye.

Orion (the Hunter) is also prominent, featuring red supergiant Betelgeuse, De Mairan's Nebula (M43) and the Orion Nebula (M42).

Using the sky chart

This chart is for use at 22:00 (GMT) mid-month and is set for 52° latitude.

01 Hold the chart above your head with the bottom of the page in front of you.

02 Face south and notice that north on the chart is behind you.

03 The constellations on the chart should now match what you see in the sky.

Magnitudes

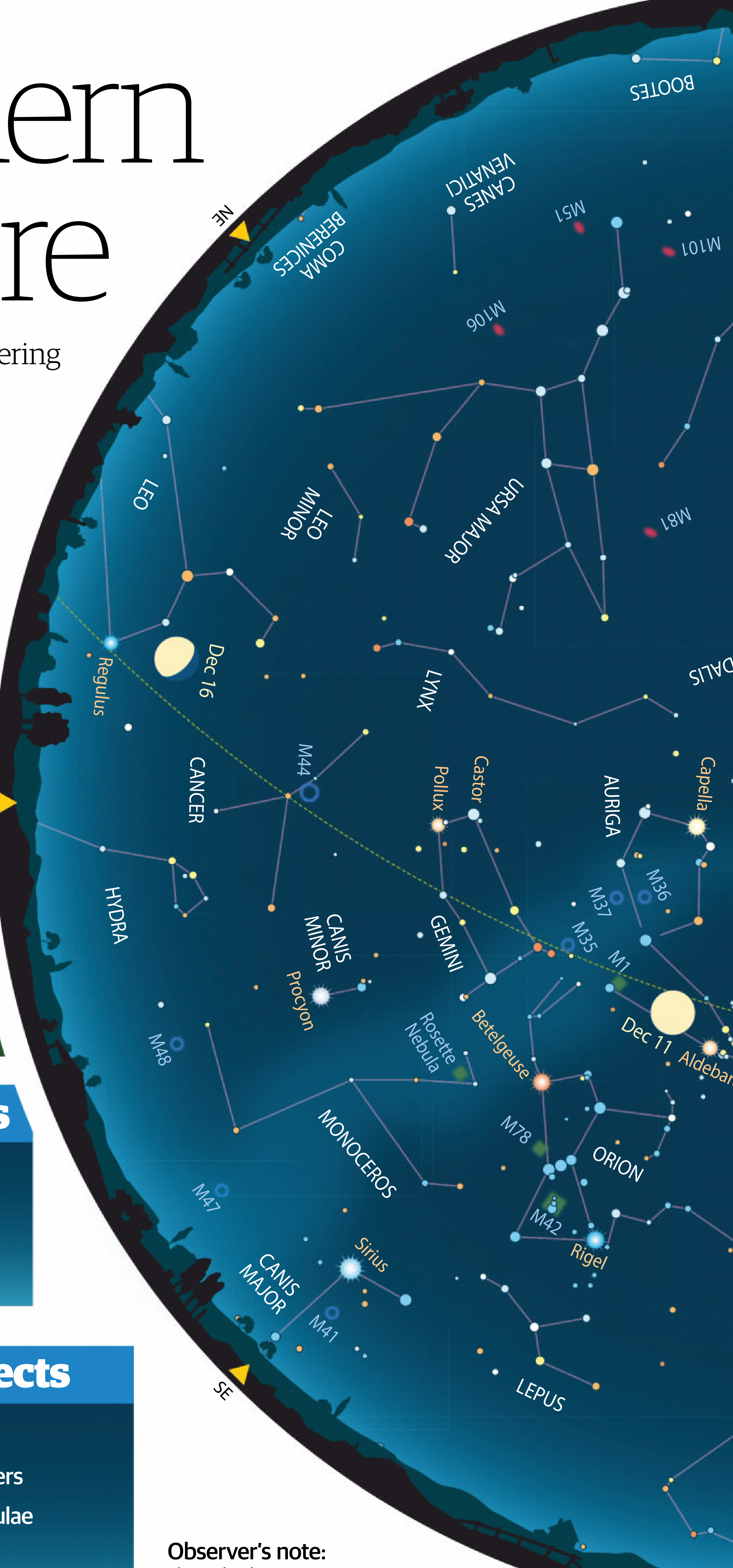
- ● Sirius (-1.4)
- ● -0.5 to 0.0
- ● 0.0 to 0.5
- ● 0.5 to 1.0
- ● 1.0 to 1.5
- ● 1.5 to 2.0
- ● 2.0 to 2.5
- ● 2.5 to 3.0
- ● 3.0 to 3.5
- ● 3.5 to 4.0
- ● 4.0 to 4.5
- · Fainter
- ◉ Variable star

Spectral types

● O-B	● G
● A	● K
● F	● M

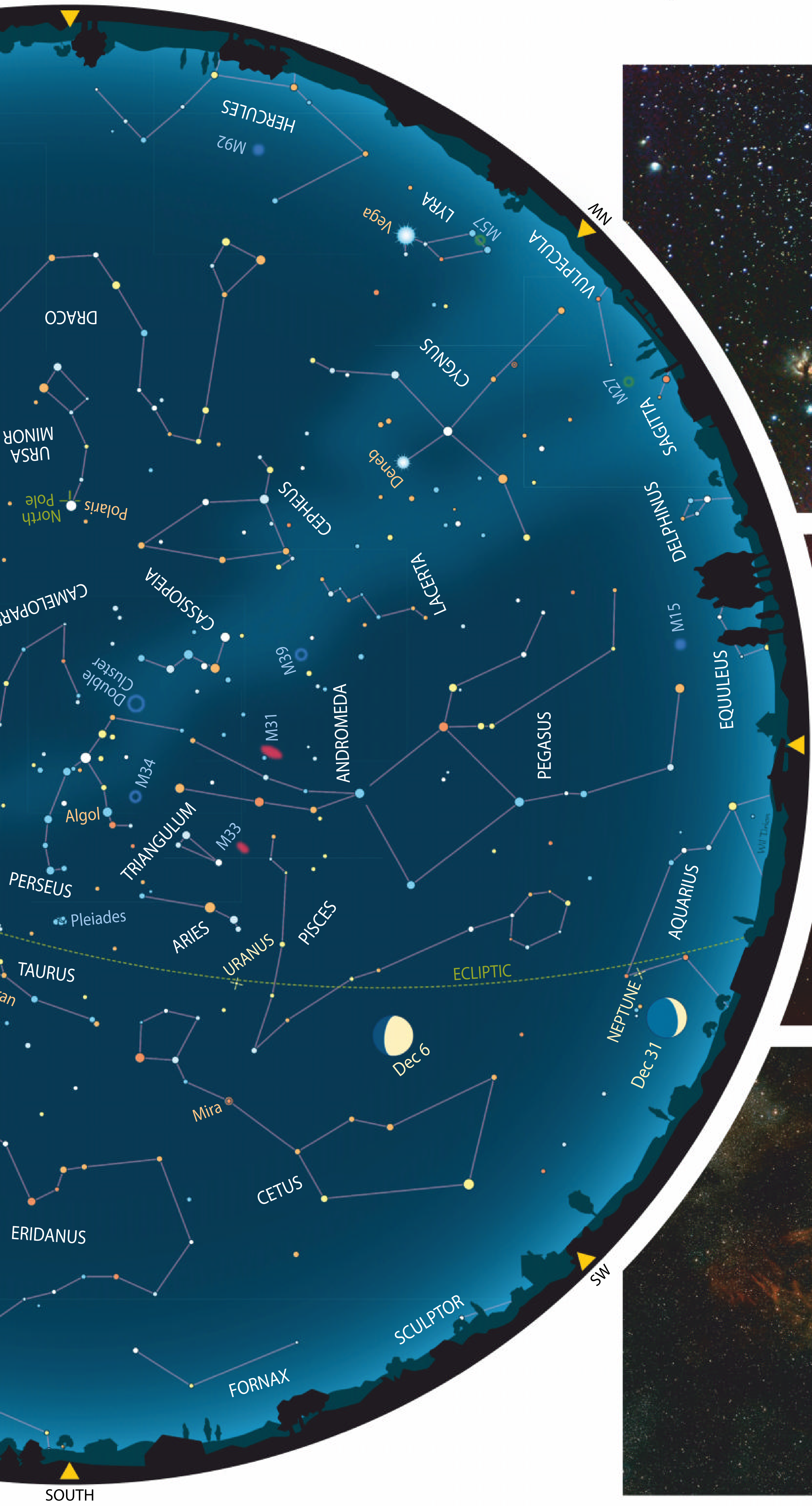
Deep-sky objects

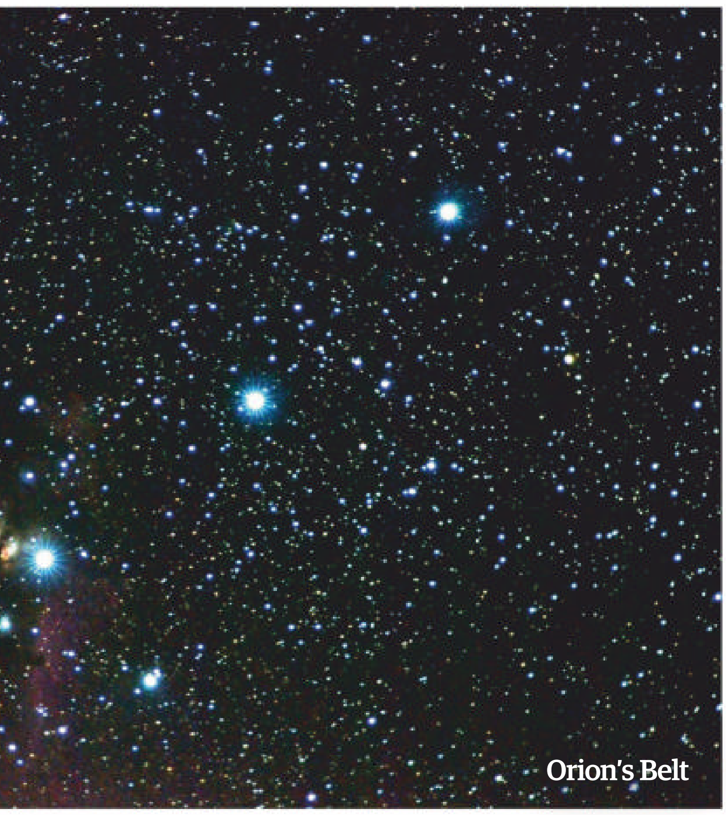
- ○ Open star clusters
- ● Globular star clusters
- ■ Bright diffuse nebulae
- ○ Planetary nebulae
- ● Galaxies



Observer's note:
The night sky as it appears on 17 December 2019 at approximately 22:00 (GMT)

The Northern Hemisphere

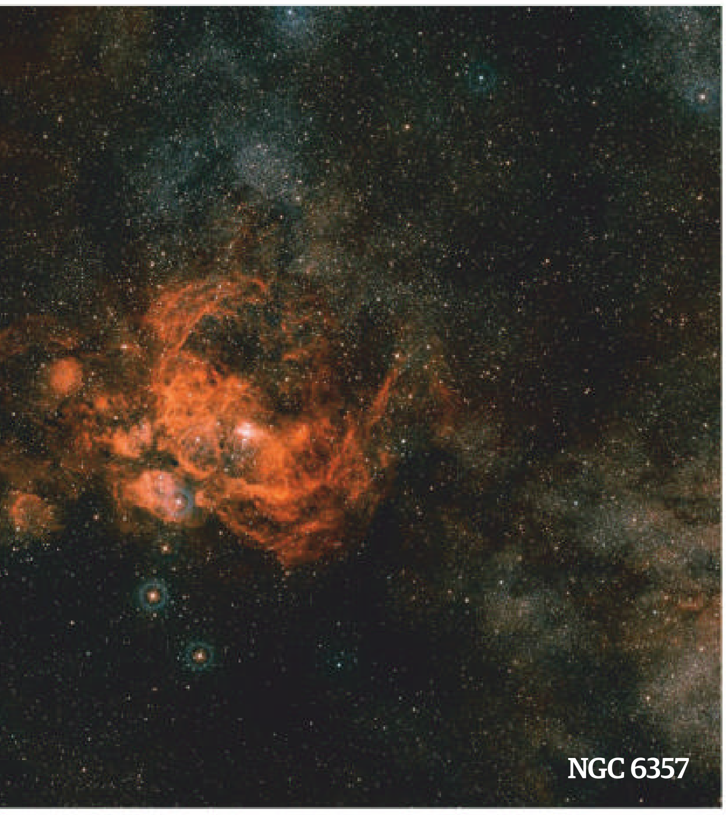



Orion's Belt

© Wiki/ myyorgda

The Cone Nebula (NGC 2264)

© ESO


NGC 6357

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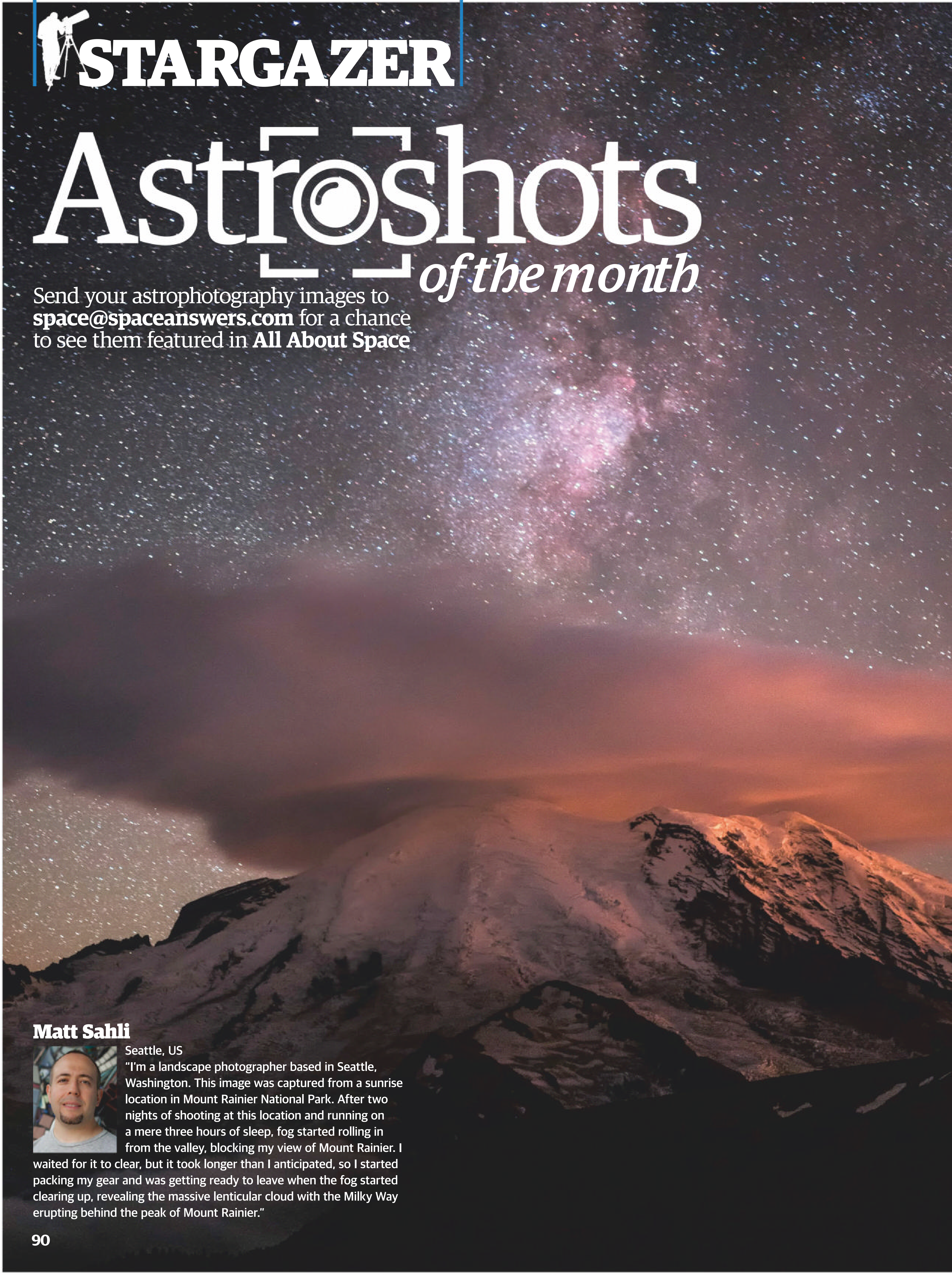
Astroshots of the month

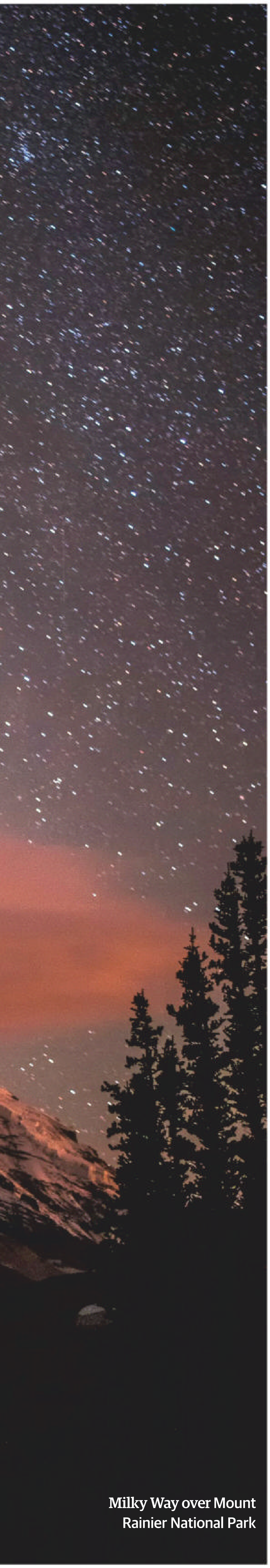
Send your astrophotography images to **space@spaceanswers.com** for a chance to see them featured in **All About Space**



Matt Sahli

Seattle, US

"I'm a landscape photographer based in Seattle, Washington. This image was captured from a sunrise location in Mount Rainier National Park. After two nights of shooting at this location and running on a mere three hours of sleep, fog started rolling in from the valley, blocking my view of Mount Rainier. I waited for it to clear, but it took longer than I anticipated, so I started packing my gear and was getting ready to leave when the fog started clearing up, revealing the massive lenticular cloud with the Milky Way erupting behind the peak of Mount Rainier."



Milky Way over Mount Rainier National Park

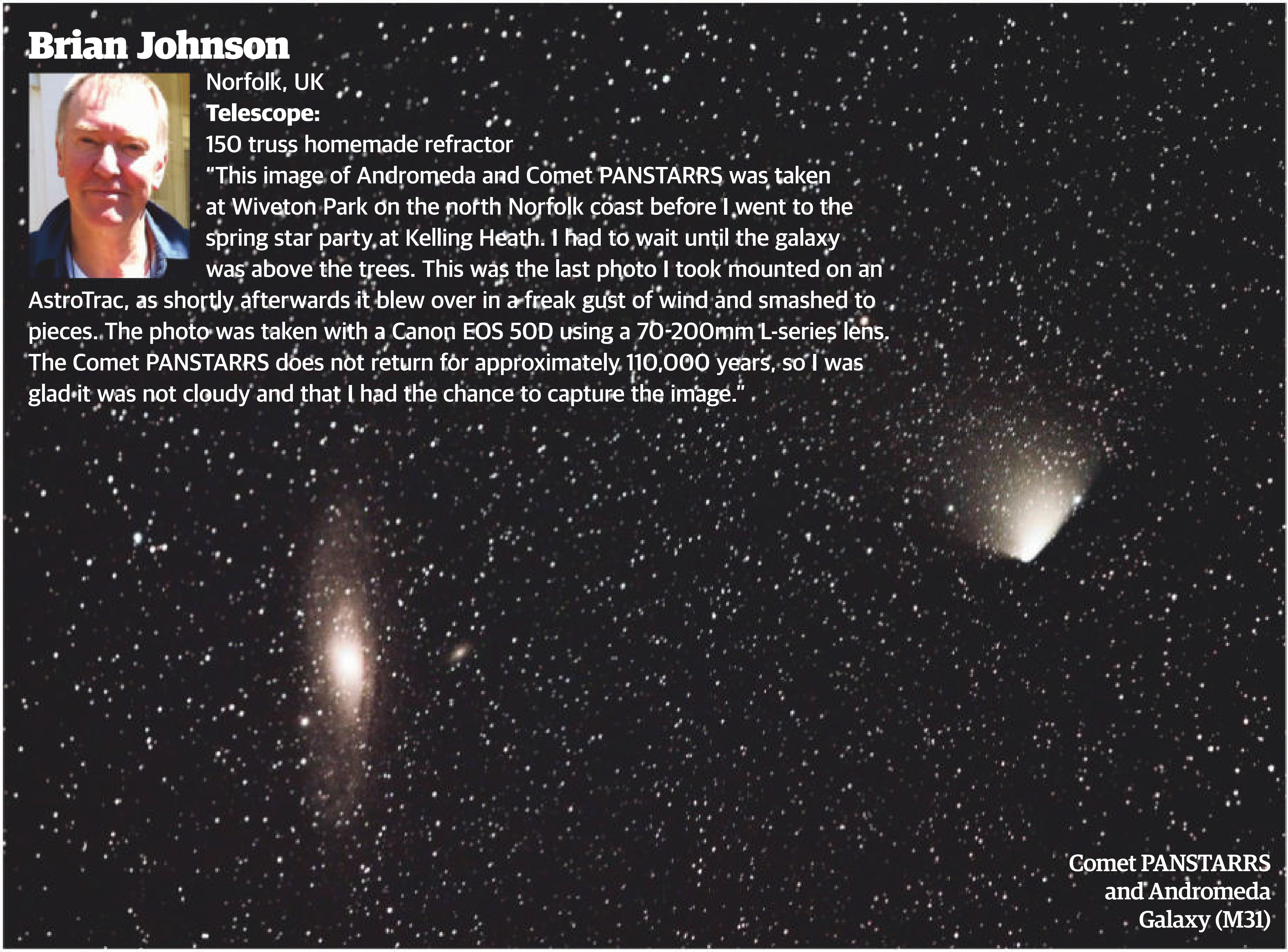
Brian Johnson

Norfolk, UK

Telescope:

150 truss homemade refractor

"This image of Andromeda and Comet PANSTARRS was taken at Wiveton Park on the north Norfolk coast before I went to the spring star party at Kelling Heath. I had to wait until the galaxy was above the trees. This was the last photo I took mounted on an AstroTrac, as shortly afterwards it blew over in a freak gust of wind and smashed to pieces. The photo was taken with a Canon EOS 50D using a 70-200mm L-series lens. The Comet PANSTARRS does not return for approximately 110,000 years, so I was glad it was not cloudy and that I had the chance to capture the image."



Comet PANSTARRS and Andromeda Galaxy (M31)

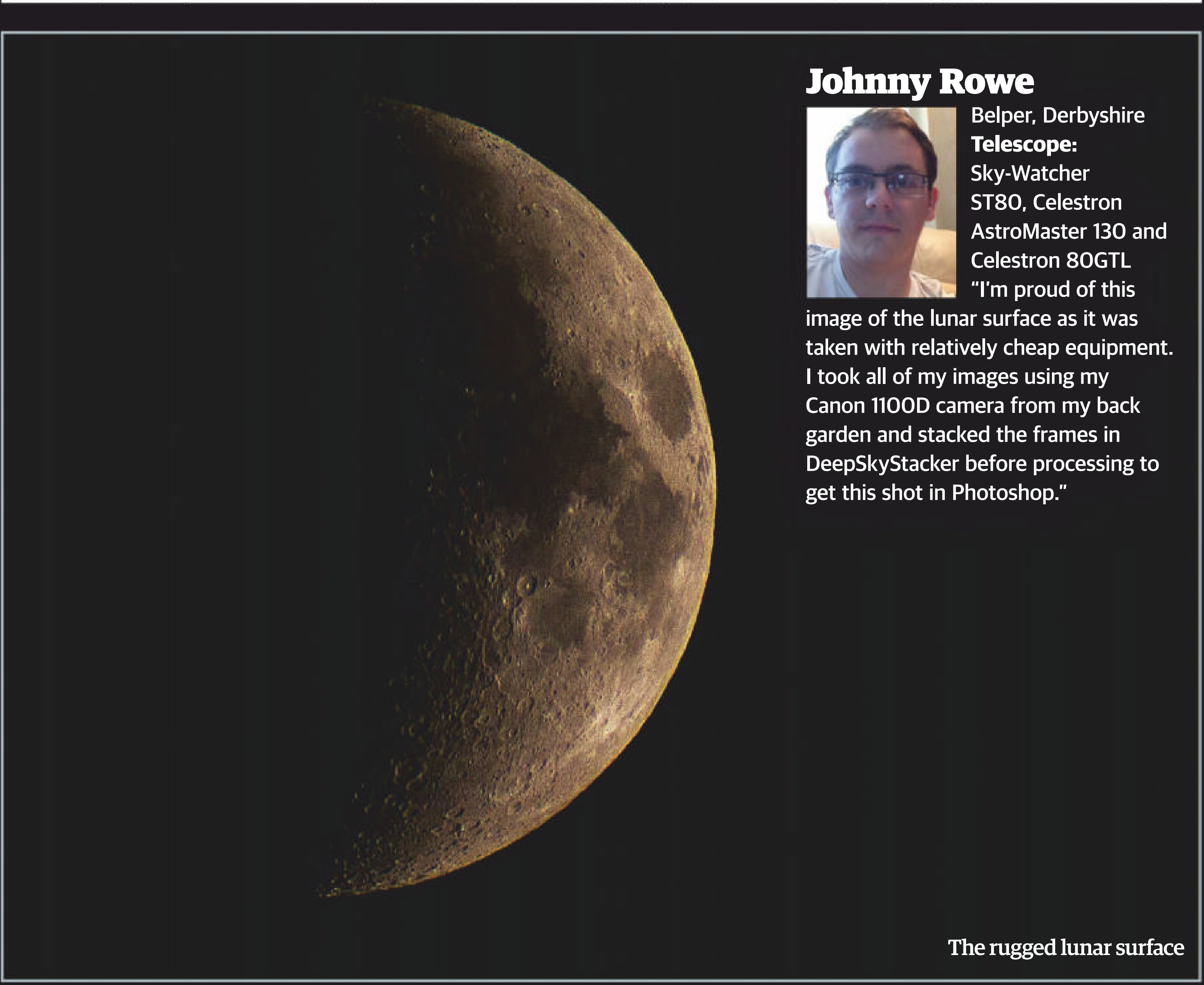
Johnny Rowe

Belper, Derbyshire

Telescope:

Sky-Watcher ST80, Celestron AstroMaster 130 and Celestron 80GTL

"I'm proud of this image of the lunar surface as it was taken with relatively cheap equipment. I took all of my images using my Canon 1100D camera from my back garden and stacked the frames in DeepSkyStacker before processing to get this shot in Photoshop."



The rugged lunar surface

Send your photos to... @spaceanswers space@spaceanswers.com

Celestron NexStar Evolution 6

This catadioptric GoTo promises accessibility for astronomers of all abilities, but does it live up to this statement for the price?

Telescope advice

Cost: £1,199 (approx. $1,930)
From: David Hinds Ltd
Type: Catadioptric/GoTo
Aperture: 6"
Focal length: 59"

Best for...

- Beginners and Intermediate
- Large budgets
- Planetary viewing
- Lunar viewing
- Deep-sky objects
- Double stars
- Limited astrophotography
- Star clusters

Ever since Celestron introduced the NexStar Evolution, we couldn't wait for its arrival at the **All About Space** office. According to Adam Hinds of David Hinds Ltd, this catadioptric instrument brings the latest technology to the already comprehensive GoTo and promises to make finding your way around the night sky simple, even if you have very limited knowledge. Not only that, but this telescope is a great way to get into astrophotography.

The assembly was a breeze, something we saw as a big plus, and certainly making this telescope a winner for beginners with quite a large budget - though we wouldn't recommend paying out for an instrument if it won't get very much use. The build of the telescope - from the tripod all the way down to the 1.25" star diagonal - is of excellent quality. The only real drawback was the StarPointer finderscope, which felt a tad flimsy. The handles, which you intuitively reach out for when you need to pick up the telescope, have been well thought out in terms of their positioning on the alt-azimuth mount, ensuring that carrying the NexStar isn't awkward to the point of causing an injury or, indeed, dropping the telescope.

Upon closer inspection we learned that there is a lithium-ion phosphate battery that you can simply recharge to power the telescope. Many GoTo telescopes have an external powerpack, but without one we quickly reaped the rewards, and it certainly was a step in the right direction for the design of this breed of telescope. Celestron has also ensured you're not restricted to having to charge up the instrument before heading outside to observe, since it has supplied a power cable that allows you to use the mount. It was nice to have the choice - and it's a manufacturing move many astronomers will benefit from.

To look at, the mount dominates the telescope. As well as the Evolution's battery, the mount houses an internal WiFi network that allows the observer to control the telescope using either a tablet or a smartphone - what's more, both Android and iOS users can utilise this feature. Once again Celestron has covered all bases, also suppling a standard GoTo controller to command the telescope if you would rather not use your device.

We were very interested in using our iPhone to control the 'scope, and we downloaded the free Celestron SkyPortal app with ease. Flicking the mount on, we were connected up to the built-in SkyQ Link WiFi in no time, and it wasn't long before we were embroiled in polar aligning the telescope - this was completed quickly and we were very impressed with the Evolution's response. The GoTo was supplied with 40mm and 13mm Plössl eyepieces of exceptional quality, which gave magnifications of 38x and 115x, respectively. Suggesting a few targets for the Evolution to find, we quickly found that while the telescope located them with no trouble at all, the objects did appear quite a small way off from the field of view's central point. Carrying out the star-alignment process again using the 13mm Plössl we were able to achieve much more accuracy. The mount was a little noisy on occasion, but this didn't bother us at all.

Popping the 40mm eyepiece back into the 'scope, we enjoyed a stunning display of craters along the lunar terminator of a final quarter Moon. We got a superb view of the crater Archimedes, which presented itself as an almost perfectly circular impact. Not too far from Archimedes, we used the 13mm Plössl to witness pleasing views of the Apennine Mountain range, where the peaks had beautifully caught the Sun's light. The Schmidt-Cassegrain's optical system truly offered the bright, sharp views that it promised thanks to the excellent StarBright XLT optical coating. Jupiter and its four largest moons - Ganymede, Io, Europa and Callisto - were also an excellent sight.

Turning our attention to the constellation Lyra, the Harp, we were able to pick out the double star Epsilon Lyrae, which can be found up and to the

"The GoTo was supplied with 40mm and 13mm eyepieces of exceptional quality"

Bottom left: The quality of the telescope is excellent - especially the eyepieces, which were of exceptional quality

Right (top): The NexStar control pad allows control of the telescope if you prefer not to use your smartphone or tablet for wireless command

Right (main): We were impressed with the optics of the NexStar Evolution, which provided mainly bright and clear views of targets and only a slight amount of coma

left of bright star Vega. The Evolution not only split the stars in this system cleanly, but also revealed a double double star system thanks to a calm atmosphere. Moving back to Vega after opting to use the NexStar's hand controller, we did detect a slight touch of coma around this 0.03-magnitude star, however, due to the impressive clarity of such a bright source, we felt that this was only a very slight flaw in the optics.

Moving over to the star Albireo in the constellation of Cygnus, the Swan, we were treated to a wonderful colour contrast as the Evolution split the double star with ease, treating us to its amber and blue-green components. Meanwhile, deep-sky object the Ring Nebula (M57) as well as the Andromeda Galaxy (M31) were also pleasing October night treats.

Studying the Evolution for astrophotography potential, the telescope offers some scope for the novice astroimager. With its alt-azimuth mount, you're in luck if you are interested in imaging the Moon and brighter planets, but only some deep-sky targets can be imaged using this telescope and with the required kit. Overall this telescope is excellent and, despite the hefty price tag, is an instrument that not only makes astronomy easy for the novice, but is a good all-rounder.

WIN

OREGON OBSERVATION 20X80

Courtesy of Opticron, these binoculars provide clear and crisp views of a selection of terrestrial and astronomical targets

The Oregon Observation 20x80 binoculars are the perfect companion – not just for viewing landscapes and wildlife on Earth – but also getting closer to a variety of planets, galaxies and star clusters that populate our night skies, as well as our own satellite, the Moon.

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B: Titan

C: The Moon

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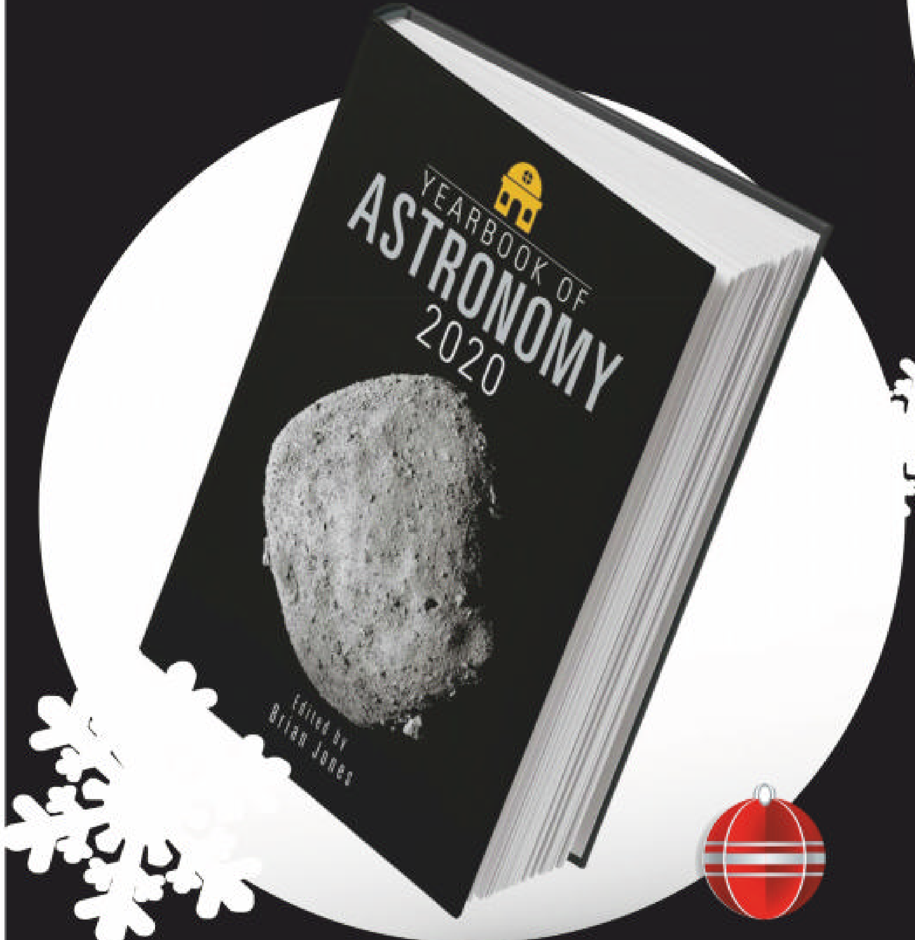
Christmas gift guide

With the holiday season officially here, **All About Space** selects the space gifts sure to delight any fan of the universe

Best for observers
Meade Adventure Scope 80

Cost: £99 (~€115.65/$127.25) **From:** Currys

The perfect gift for lovers of the great outdoors, the adventure starts here this Christmas with the travel-ready Meade Adventure Scope 80. Functioning as both a telescope and daytime spotting scope, the generous 80mm aperture and red-dot finderscope provide superior views of wildlife, landscapes, celestial objects and more, with exceptional viewing clarity and smooth tracking precision. Compact in design, the Meade Adventure Scope 80 can be assembled in seconds, packing away into the included lightweight backpack along with aluminium tripod and eyepieces. Camping, hiking, exploring the outdoors or in the comfort of your own back garden, enjoy instant on-the-go viewing whenever the wilderness calls.



> "Compact in design, the Meade Adventure Scope 80 can be assembled in seconds"

Best for armchair astronomers
Yearbook of Astronomy 2020

Cost: £16.99 (~€20.00/$21.80)
From: Pen & Sword Books

The *Yearbook of Astronomy* continues to be essential reading for anyone lured and fascinated by the magic of astronomy and who has a desire to extend their knowledge of the universe and the wonders it plays host to. An inspiration to amateur and professional astronomers alike, the *Yearbook of Astronomy* warrants a place on the bookshelf of all sky-watchers and stargazers.

Best for Moon landing fans
Haynes Owners' Workshop Manual Apollo 11

Cost: £22.99 (~€26.90/$29.60)
From: Haynes Publishing

It tells the story of the Apollo 11 mission, including the evolution and design of the mighty Saturn V rocket, the Command and Service Modules and the Lunar Module. This special anniversary edition also looks at the legacy of Apollo 11 and the manned Moon missions and deep-space exploration of the future.

Best for spaceflight fans
Apollo 11

Cost: £25.00 (~€29.20/$32.15)
From: Pen & Sword Books
Half a century has passed since arguably the greatest feat of the 20th century: when Neil Armstrong became the first man to walk on the Moon. *Apollo 11: The Moon Landing in Real Time* brings the mission back to life as never before in a thrilling day-by-day account, exploring everything from the historic flight itself to how the $24 billion space programme divided a nation.

Best for tours of the night sky
Stars and Constellations Glow Map

Cost: £20.00 (~€23.40/$25.70) **From:** Maps International
Packed with fascinating information on the cosmos, it includes detailed constellations and illustrations of planets in our Solar System, plus satellites, lunar positions, eclipses, meteors and comets. Printed with glow-in-the-dark ink that charges with light during the day, it glows for approximately 12 hours at night. **All About Space** readers can get 20 per cent off with the code AASPACEMAP10.

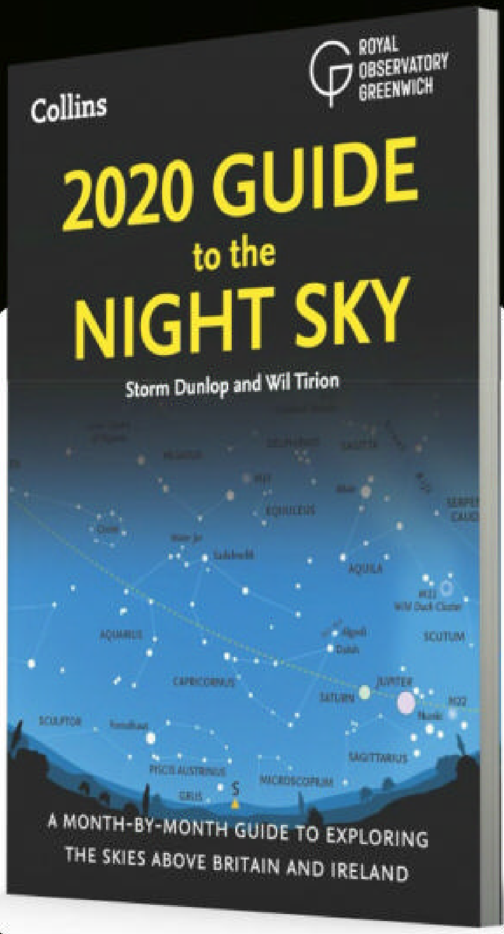
Best for stargazing
2020 Guide to the Night Sky

Cost: £6.99 (Paperback) (~€8.20/$8.99)
From: Collins

Look to the stars in 2020 with the bestselling month-by-month guide to the night sky visible from Britain and Ireland. Written by astronomy experts at the Royal Observatory Greenwich, the guide is full of easy-to-use star maps and information on what to look out for, plus new seasonal charts, details of dark-sky sites and charts for positions of planets and comets in 2020.

Best for lunar observers
The Moon: A Celebration of Our Celestial Neighbour

Cost: £20.00 (~€23.40/$25.70)
From: Collins
Marking the 50th anniversary of Neil Armstrong's 'small step', this beautiful book explores people's fascination with our only natural satellite. Published to coincide with Royal Museums Greenwich's exhibition The Moon, immerse yourself in contemporary essays and fascinating images wrapped in a sleek design and edited by the exhibition's curators, Melanie Vandenbrouck, Megan Barford, Louise Devoy and Richard Dunn.


Collins
ROYAL OBSERVATORY GREENWICH
2020 GUIDE to the NIGHT SKY
Storm Dunlop and Wil Tirion
A MONTH-BY-MONTH GUIDE TO EXPLORING THE SKIES ABOVE BRITAIN AND IRELAND

Kurt H. Debus

A former German rocket scientist now considered the father of the Kennedy Space Center

Debus became director of the Kennedy Space Center in 1962

© NASA

As World War II came to its conclusion in 1945, the United States swiftly moved to perform Operation Paperclip. The aim of the operation was to recruit as many Nazi scientists as possible in anticipation of the Cold War with the Soviet Union. One of the scientists swooped up in this operation would later become a monumental figure at the John F. Kennedy Space Center.

Born on 29 November 1908 in Frankfurt, Germany, Debus was an electrical engineer by trade, gaining a bachelors, masters and doctorate degree in the field at Technische Hochschule Darmstadt, the Technical University of Darmstadt, Germany. Soon after he became part of the Nazi Party's attempt at creating a ballistic missile, known as the V-2 rocket, along with famous Nazi-turned-US scientist Wernher von Braun - a pioneer of rocketry and space science and engineering. After the war Debus - along with 1,600 other scientists - was relocated to the United States and carried on the work designing rockets and missiles.

Debus adjusted to US life, first working at Fort Bliss in Texas before relocating again to Huntsville, Alabama. In the late 1940s and 1950s, Debus and his team were making headway with the new Redstone missile programme, with new facilities being built for it at Cape Canaveral, Florida. However, missiles were no longer the focus in the 1960s, as the United States President at the time, John F. Kennedy, announced they would instead aim for the Moon.

During this period the ballistic missile launch site at Cape Canaveral was transferred to the National Aeronautics and Space Administration (NASA), and the site was renamed NASA's Launch Operations Center. This was later changed to honour the assassinated president who laid the foundations for this historic adventure, and it has been called the John F. Kennedy Space Center ever since.

Debus was the figurehead in the assembly, construction and development of the spaceport, including its launch pads and Vehicle Assembly Building, which is still the tallest single-story building in the world, standing at 160 metres (530 feet). Debus officially became the first centre director, and continued to operate the Kennedy Space Center for 12 years, leading the institute during arguably its most fruitful period until his retirement in November 1974.

Debus and von Braun have been credited as the dynamic duo that played a huge part from the ballistic missile programme through to the United States' aim to get to the Moon, with von Braun building the rocket and Debus building the spaceport it would launch from.

Due to his incredible service to the United States, Debus received its highest civilian decoration, the Exceptional Civilian Service Medal, adding to his awards that include the Commander's Cross of the order of merit of the Federal Republic of Germany, NASA's Distinguished Service Medal - awarded twice: once for Apollo 8 and again for Apollo 11 - and was elected into the National Space Hall of Fame. There is even a 'Debus Award' - started in 1990 by the National Space Club Florida Committee (NSCFL), it is awarded to an individual who has stood out in its aerospace efforts.

> "Debus adjusted to US life, first working at Fort Bliss in Texas before relocating again to Huntsville, Alabama"

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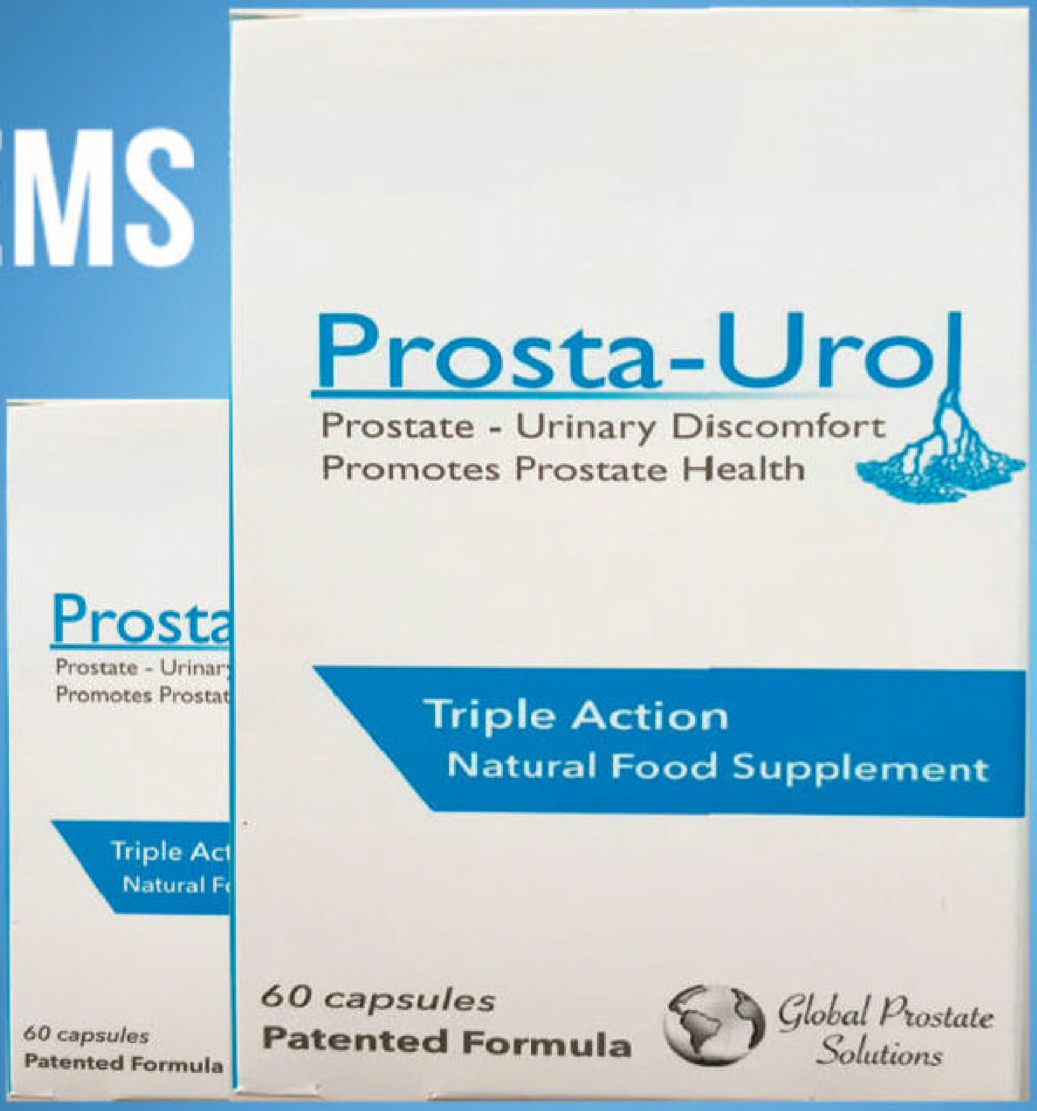

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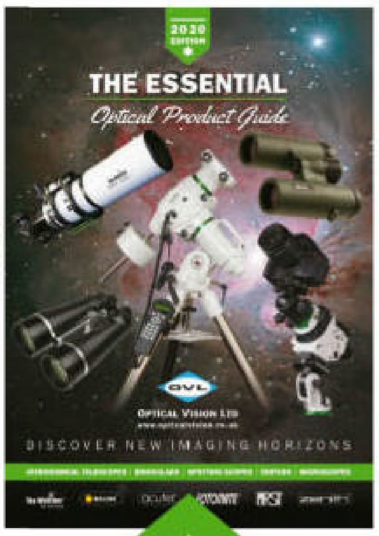

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